Dublin Region Energy Master Plan

Key findings for decarbonising Dublin's heat, electricity and transport sectors towards 2030 and 2050

SUSTAINABLE ENERGY AUTHORITY OF IRELAND

Dublin Region Energy Masterplan

Report prepared by Codema

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Executive Summary

The Dublin Region Energy Masterplan is a project funded by the Sustainable Energy Authority of Ireland's (SEAI's) Research, Development and Demonstration (RD&D) Funding Programme 2018. Codema has been leading the project and collaborating with the four Dublin Local Authorities to establish the first regional energy masterplan in Ireland. The masterplan provides realistic, costed pathways for the Dublin Region to achieve its carbon emission reduction targets to 2030 and 2050. These pathways have been based on detailed local-level, spatially-driven energy scenario modelling and identify low-carbon technologies specific to the energy characteristics of a particular area at a local level, which has not been carried out before for any county in Ireland. To do this, the masterplan brings together and amalgamates, for the first time, all the relevant government and various energy-related departments' plans and policies together to show their impact at a county/local level.

This masterplan focuses on the Dublin region; Dublin City, Dún Laoghaire-Rathdown, Fingal and South Dublin, and takes a holistic approach to energy modelling, which allows for better, more cost-effective solutions than looking at separate sectors in isolation. The masterplan addresses all energy sectors of electricity, heat and transport, and crucially has been modelled from a spatial perspective as well as from a technology perspective. This project also identifies and supports the use of low-carbon sources indigenous to Dublin, develops and harnesses new local-level energy policy practices, and strengthens Ireland's integrated energy system modelling capabilities. Two baseline scenarios have been established; the current situation and the future 'business-as-usual' situation, which models the effects of current national level policy implementation to 2030 and 2050. From these, Codema then established the gap-to-targets, and evaluated the possible local-level low-carbon pathways to meet these targets. The low-carbon potential of Dublin has been based on its unique spatial energy characteristics, which are often overlooked when examining low-carbon pathways at a national level.

At a local level, local authorities have to meet a number of legal climate action obligations and targets, and the results of this work have already helped and will continue to help support the DLAs to meet these obligations by taking action on climate and meeting their policy requirements in areas such as:

- Preparation of **County/City Development Plans**
- Identification of **Strategic Energy Zones**
- Assessment of **Decarbonising Zones**
- Preparation of **climate mitigation plans**
- Roll out of **low-carbon infrastructure** (district heating, electric vehicle (EV) charging, etc.)
- **Carbon and energy assessment** of planning applications
- Creation of EU Covenant of Mayors **Sustainable Energy and Climate Action Plans**

The results of the DREM will allow local authorities to effectively create evidence-based policies and actions, which will affect CO_2 emissions county-wide, by using the local authorities' powers in spatial planning, land-use, planning policy and public infrastructure.

This holistic approach to analysing in-depth the local energy characteristics of the Dublin Region takes account of such aspects as the building stock's efficiency and energy demand, the capacities of local electricity infrastructure, land-use constraints and availability, transport network capacities and vehicle use, and layered with expected population and development growth. It also examines the potential for local renewable and low-carbon generation of heat, electricity and renewable fuels in Dublin.

To define the Dublin Region's decarbonisation pathways and help the region to meet its 2030 and 2050 targets, Codema first had to get a good understanding of the current situation in the region; this was followed by projecting the future business-as-usual energy demand and emissions (for the building, heat, electricity and transport sectors), followed by the identification of low-carbon potential for the different sectors in the region. This could then all be used to determine the net-zero pathway for Dublin.

The **current spatial energy demands and emissions**, which include the current energy efficiency of buildings, heat and electricity demands and peak loads, transport demand and modal split, provided Codema with information on the energy use and emissions from the different sectors, along with current technologies that are in use.

- **Heat** accounts for the majority of emissions within the Dublin region at **46%**, followed by **transport at 28%** and **electricity at 26%.**
- The sectors that have the highest impact on emissions are the **residential and transport sector,** which combined, contribute around **57% to total emissions**.
- Commercial buildings and services, data centres and industrial (non-ETS) buildings, account for 19%, 16% and 3% of total emissions, respectively.
- **Public sector emissions** - which includes all public buildings located in the Dublin Region - represents approximately **5% of the total**.

This detailed energy and emissions information was then used to give insight to the current gap for Dublin to meet its 2030 and 2050 targets. The **2030 target** corresponds to a **51% reduction from 2018** figures, as defined by the Programme for Government[1], which states that Ireland is 'committed to an average 7% per annum reduction in overall greenhouse gas emissions from 2018 to 2030 (a 51% reduction over the decade)'. The **2050 target** is for **net-zero energy-related GHG emissions**, in line with the overall target set in the Climate Action Plan 2021.

The headline figures from this masterplan show that:

- Dublin's **total energy-related emissions** account for **5,969 $ktCO_2$**
- The current **gap to the 2030 target** amounts to approximately **2,856 $ktCO_2$** (requiring a 48% reduction in emissions from current levels)
- A reduction of **5,969 $ktCO_2$** will be needed to meet the **2050 net-zero target**

Based on current energy demand and emissions, Codema projected the future Business-as-Usual (BaU) scenario. This forecast accounts for increases in population, new buildings to meet this population increase in both the housing stock and commercial properties in future years, whilst also considering the negating effects of increased energy efficiency in existing buildings and the rebound effect on theoretical energy demand reductions. For the increase in population, it also assumes that the share of new car sales by fuel type would remain constant and increase to 2050. Overall, projections to 2030 and 2050 in a BaU scenario show that emissions are expected to increase, a breakdown of this can be seen below:

- **Emission projections to 2030 will increase by 21%**
- **Emission projections to 2050 will increase by 33%**
- **Transport emissions will increase by 13%** by 2050 (from 1,664 $ktCO_2$ to 1,884 $ktCO_2$)
- **Emissions from buildings** (including heat and electricity) **will increase by 41% by 2050** (from 4,307 $ktCO_2$ to 6,062 $ktCO_2$)

The figure below shows the gap-to-target (i.e. difference between the projected business-as-usual emissions and the target emission levels), which is represented by the dotted lines. It also outlines the technology adoption levels required to meet these targets. The technology options are prioritised in this graph starting with the least-cost carbon reduction option at the top and the highest cost technology option at the bottom. It should be noted that some of these technologies should be considered in conjunction with one another and not in isolation, for example Heat Pumps and Building Fabric Upgrades.

[1] https://www.gov.ie/en/publication/7e05d-programme-for-government-our-shared-future/

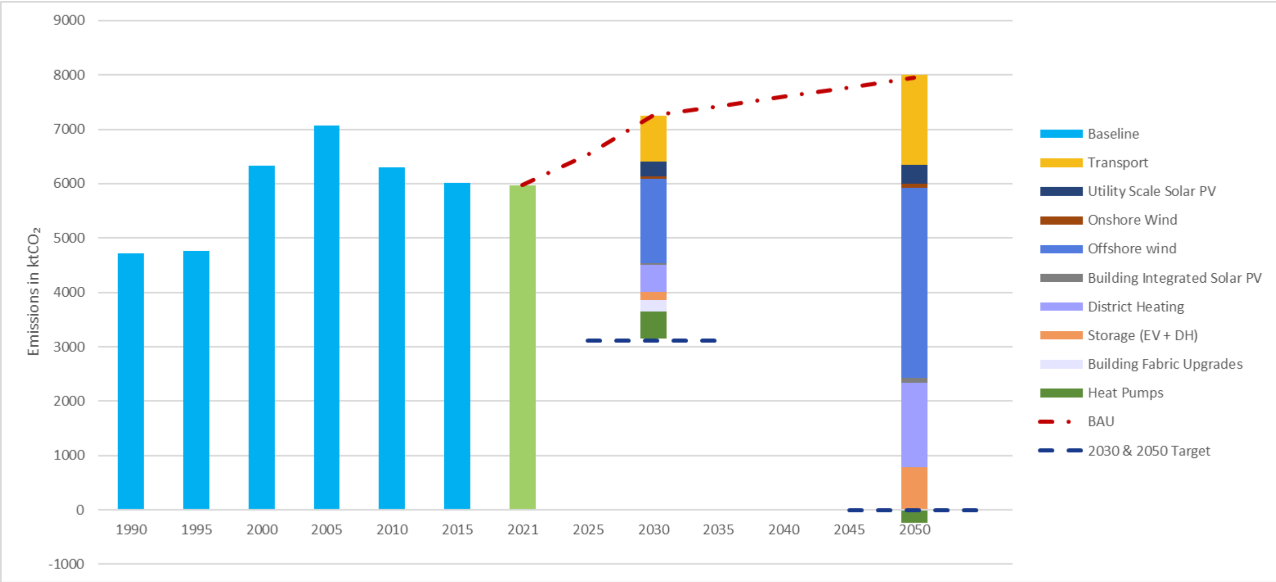

Figure 1: 2030 and 2050 low-carbon and net-zero pathways

Key findings and recommendations that have been identified based on the pathway set out in this masterplan report are presented below:

Energy Planning

- **Guidelines for local level energy planning** need to be made available to municipalities
- **Energy planning should become a requirement** for implementing local-level energy plans with clear pathways and long-term commitments to a low-carbon future
- In order to support more cost-effective and sustainable development of infrastructure (electricity grid, heat networks, transport infrastructure, etc.) **higher building density should be promoted within the county**
- A **GIS-based database of low-carbon technology installations** within the County should be maintained. This should include information on the size, type, grid connection details (where applicable) and energy generation (kW peak, annual kWh) of each installation. This will allow tracking of progress toward targets and updates to allow pathways to respond to future cost fluctuations and account for proportion of identified potential that has been realised

Building Energy Efficiency

- To alleviate energy poverty, the county should consider **prioritising energy efficiency upgrades in areas that have been identified in this masterplan as being energy poor**. These areas include Ballybough, Cabra, Clondalkin, Clonskeagh, Finglas, Inns Quay, Kilmore, Priorswood, Decies, Drumfinn, Inchicore, Kilmainham, Kimmage, Kylemore, Merchants Quay Tallaght, and Wood Quay.
- Regulatory solutions to tackle the issue of split incentives should be considered, with **minimum energy efficiency standards for rented properties being applied** and structures should be in place that facilitate landlords to achieve this; this should also address **funding mechanisms** for energy efficiency upgrades, particularly addressing long payback periods and high upfront costs in both the residential and non-residential sector.
- In order to facilitate more accurate forward planning, it is recommended that a **simple energy assessment form be submitted with all planning applications**. This form should include general information relating to energy use within the development such as annual and peak demand for heat and electricity, floor area, BER, heating system details, details of renewables on site, EV charging details, etc.

Heat

- **District heating represents the most feasible low-carbon heating option for 87% of heat demand in Dublin by 2050** this equates to **538,983 homes and 41,394 businesses being heated by DH**. **Heat pumps are the most feasible option for 13% of the heat demand in Dublin by 2050 serving 72,528 homes and 5,600 businesses**.
- Heat sources that arise as a by-product of electricity generation, industrial activity, the natural environment or from existing infrastructure are low or zero-carbon and often go to waste. Codema estimates that **3,579 MW of heat is available from these sources (including both low-grade and high-grade heat) that could be utilised via district heat networks in Dublin, equating to 24,244 GWh of heat per annum, enough to heat over 1.6 million homes.**

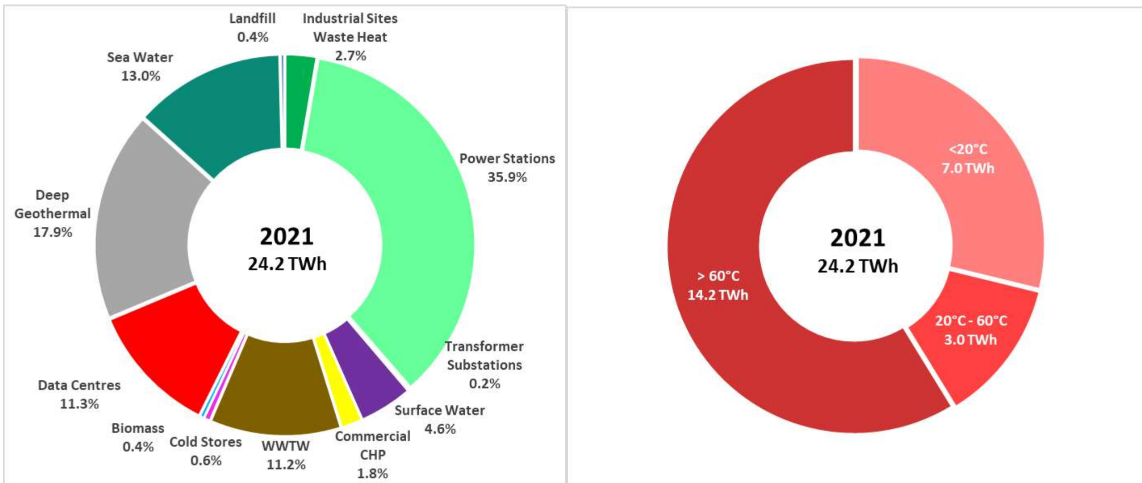

Figure 2: Current breakdown of potential heat sources for district heating networks

- Evidence-based **zoning for district heating** should be introduced and **requirements put in place for buildings in these areas in relation to connection, future-proofing on both the demand and supply side, characterising heat sources (waste heat reports)**
- **Ensure low-carbon heat sources including waste heat are treated fairly in Part L building regulations** (in line with Articles 15 and 23 of the Renewable Energy Directive)
- Make **financial support** more easily available for these low-carbon solutions. Provision of up-front capital grant funding for low-carbon heating. **Make low-carbon district heating networks eligible to earn credits under the proposed renewable heat obligation (RHO).**
- **Review the heat loss threshold required to secure grants for heat pumps -** look at potential for increasing the allowable heat loss index to allow more homes to be eligible for support but without exceeding limits that would result in poor heat pump performance. The basis for such an analysis can be provided by the Irish Building Stock Generator developed as part of this study[2].
- Introduce **customer protection for district heating**
- Support **capacity building** across the supply chain for both DH and heat pumps (planning, construction & installation, design, finance, legal, policy and regulation, etc.)
- Support the adoption of **business models in heating which support ongoing efficient and reliable performance of heating systems by linking installer revenues to ongoing system performance**
- **As a high-exergy fuel, gas (including natural gas, hydrogen etc.) should not be used for low-exergy applications like space heating and hot water preparation** where more efficient and lower-carbon alternatives exist (e.g. heat pumps, district heating). In the case of hydrogen some uncertainties remain in relation to its viability in the short to medium term which are discussed further in Appendix C.

Electricity

- **Support the development of generation assets**, particularly in areas with high suitability identified in this report. **Offshore wind represents the greatest renewable electricity generating potential in the Dublin area**

[2] https://github.com/codema-dev/rc-building-model

with an estimated 5,241 GWh of generation by 2030 and 13,124 GWh in 2050**. Utility-scale solar PV represents the second biggest renewable electricity generating opportunity in Dublin with potential estimated at 854 GWh in 2030 and 1,057 GWh in 2050. Onshore wind has 130 GWh of potential by 2030 and 325 GWh by 2050[3] in the upland areas in the south of the county.

- **Development of enabling infrastructure** needs to be supported to realise renewable potential.
- Promote the adoption of **building integrated PV, particularly in buildings where demand and production profiles match**. The opportunity for building integrated PV in Dublin is estimated at 84GWh in 2030 and 270GWh in 2050 which equate to the electrical demand for 19,984 and 64,394 homes respectively[4].
- For **significant energy users** such as data centres, ensure that **these consumers take actions to reduce their climate impacts**, including:
    - **Maximising on-site renewable generation** and ensuring **remaining demand is supplied via renewable PPAs** (preferably those which match hourly site demand), which finance renewable electricity projects **within Ireland or its territorial waters**
    - Ensure that any **waste heat produced on site is characterised and made available for use in existing or planned DH networks** - this reduces onsite electricity and water consumption for cooling systems and can make use of waste heat from on-site generators which may be needed to support the grid in high demand periods
    - Ensuring that data centre and other large electricity consumers **impact on the grid is minimised**. This will be assessed by relevant parties such as EirGrid in accordance with Data Centre grid connection processing procedure to ensure that grid integrity is maintained. Connection to district heating networks can also reduce the electricity demand associated with cooling data centres and in heating the buildings connected to the network when compared with individual heat pumps

Transport

- **Cars account for 65% of transport emissions in Dublin** and may be costing the county up to **€2.8 billion per year in external societal costs**. Simply aiming to replace the existing 550,000 cars in Dublin with EVs would represent a huge missed opportunity to create a healthier, safer and more equitable transport system and society. **Reducing car dependency and enabling a shift to active travel and public transport needs to be the number one priority**, followed by the electrification of a reduced car fleet.
- **Active travel is the simplest, quickest and most cost-effective way to decarbonise urban mobility**, particularly for shorter journeys**. E-bikes can significantly increase the range over which active travel is possible, and are now the fastest growing form of electric mobility in Europe.**[5] Dublin is a highly urbanised county, with huge potential for active travel if the appropriate policies are implemented.
- The Government's Five Cities Demand Management Study, published in 2021, identified the **'15 Minute Neighbourhoods'** concept as the number one measure that should be prioritised in order to address the carbon emissions, congestion and air quality issues in Dublin. To help enable this, City and County Development Plans should consider adopting a strict limit on the distance between new developments and regularly used amenities (e.g. shops, schools etc.) with good **permeability for active and public transport** between both. A **default 30 km/h limit** should be designated in built up areas of the County, with exceptions for specific roads, as required by the UN Stockholm Declaration of 2020.
- Transport policy to 2030 **must focus on improving active travel and bus infrastructure and services**, in order to enable the significant modal shift required towards these more sustainable modes. The planned new Metro and Luas projects are extremely expensive in comparison, and none of these will be completed in time to assist towards our 2030 targets.
- **Additional powers are required** to allow local authorities **to reallocate public space to more sustainable modes** and to implement low-traffic neighbourhoods or filtered permeability schemes. Reallocating public space away from motor traffic can also provide additional safe space for nature, for people to socialise and for

[3] This does not screen out sites based on land character assessment (visual impact)
[4] Based on average electrical consumption from the CRU of 4,200kWh per year - https://www.cru.ie/wp-content/uploads/2017/07/CER17042-Review-of-Typical-Consumption-Figures-Decision-Paper-1.pdf
[5] https://transport.ec.europa.eu/system/files/2021-12/com_2021_811_the-new-eu-urban-mobility.pdf

children to play. **Legislation to provide for experimental road traffic orders**, allowing for trials of 6-18 months, should be enacted.

- The spending of billions of Euro on bus corridors and active travel infrastructure will have been in vain if existing road traffic regulations are not enforced. **Traffic wardens, fixed cameras and bus-mounted cameras using ANPR technology** must be employed on a large scale to detect and fine motorists who create danger or delays to active travel and public transport users. A **web portal** allowing members of the public to **upload footage of dangerous and/or illegal road user behaviour** to An Garda Síochána must also be developed without delay.
- **Remote working and high-speed broadband** may enable significant reductions in transport demand and emissions by reducing the distance and number of commuting journeys. However, further analysis is required to **compare this reduction in transport emissions against the corresponding increase in domestic heating demands**. The development of **co-working hubs** and accelerated rollout of high-speed broadband throughout the county may provide a good balance in this regard, and should be supported and prioritised.
- **Electrification of transport is necessary but not sufficient** to meet our energy and emissions targets. If the 2030 EV sales targets set out in the CAP 2019 (scaled proportionately to Dublin) are met, this could reduce CO_2 emissions from transport in Dublin by at best 33%. This in itself will be a very challenging target to meet. The pathway taken in this analysis to achieve a 51% reduction by 2030 will additionally **require a minimum 23% reduction in the distance travelled by fossil-fuelled cars in Dublin**.
- EV charging infrastructure needs to be provided in a manner which **does not prioritise private motor vehicles over active travel or public transport users** and which will facilitate a significant shift away from car use. Up to **4,600 rapid (50-150 kW) charge points** may be required by 2030 to meet the demands of 213,000 BEVs.

<u>Socio-Economic</u>

Codema has recommended ways to reduce emissions in the county. If the Dublin Region were to carry out all the suggested recommendations, it could potentially:

- Reduce emissions by **4,103 ktCO_2 by the year 2030**
- Reduce emissions by **8,240 ktCO_2 by 2050**
- Increase **renewable electricity** generation in the Dublin Region by **14,780 GWh** by 2050.
- Become **a net-exporter of energy** by 2050 - it is assumed that these exports offset more carbon intensive generation elsewhere in the country and therefore allow Dublin's energy system to become carbon negative in 2050 (-295 ktCO2)
- **Decrease electricity production costs by a total of €519 million** per year by adopting **renewable energy technologies** (onshore and offshore wind, utility scale solar PV and building integrated solar PV)
- The **net zero scenario will result in €24 billion less in external societal costs than the BAU scenario** when accounting for the shadow price of carbon (and as shadow price of carbon is likely to be revised upwards, this figure could increase)
- Increase **direct jobs by over 182,500 by 2050**

Introduction

The Dublin Region Energy Masterplan is a project funded by the Sustainable Energy Authority of Ireland's (SEAI's) Research, Development and Demonstration (RD&D) Funding Programme 2018. Codema has been leading the project and collaborating with the four Dublin Local Authorities (DLAs) to establish the first regional energy masterplan in Ireland. The Dublin Region Energy Masterplan (DREM) is an authoritative evidence-base to support and inform policy making. The masterplan provides realistic, costed pathways for the Dublin Region to achieve its carbon emission reduction targets to 2030 and 2050. These pathways have been based on detailed local-level, spatially-driven energy scenario modelling and identify low-carbon technologies specific to the energy characteristics of a particular area at a local-level, which has not been carried out before for any county in Ireland. This innovative local-level energy planning methodology builds upon leading international-class energy research in the area, and findings from the DREM have already been directly applied and demonstrated by the Dublin Local Authorities. Other public bodies and local authorities can learn from the results and outcomes, and the Dublin Region Energy Masterplan will become the catalyst for similar energy planning practices in other regions across Ireland. The resulting masterplan will, importantly, also inform the energy sector and the general public as to the possible low-carbon future for Dublin and increase cooperation opportunities and general awareness.

The masterplan addresses all energy sectors of electricity, heat and transport, and crucially has been modelled from a spatial perspective, technology perspective and also from a socio-economic perspective. This project also identifies and supports the use of low-carbon sources indigenous to Dublin, develops and harnesses new local level energy policy practices, and strengthens Ireland's integrated energy system modelling capabilities. Two baseline scenarios have been established; the first being the current situation and the future 'business as usual' situation, which models the effects of current national level policy implementation to 2030 and 2050. From these, Codema then established the gap-to-targets, and evaluated the possible local level low-carbon pathways to meet these targets. The low-carbon potential of Dublin has been based on its unique spatial energy characteristics, which are often overlooked when examining low-carbon pathways at a national level. This project is the first of its kind in Ireland, and aligns with the objectives outlined in national level energy and climate change policy.

The DREM has evaluated and outlined the cost-optimal, spatially possible and technically feasible low-carbon scenarios for Dublin to meet its emission reduction targets from the perspective of society, energy consumers and the energy sector. These scenarios present a set of clear, evidence-based pathways, which will enable the Dublin region to create effective, long-term energy policy in areas such as spatial planning, land-use, and public infrastructure.

The Need for Spatial Energy Planning

The need for this energy masterplan was identified by the four DLAs through their work with Codema on their Climate Change Action Plans 2019-2024. The Climate Change Action Plans highlighted the fact that most CO_2 abatement activities planned by the local authorities only affect CO_2 that is a direct result of their own activities, i.e. their own buildings, fleet, and land. The CO_2 emissions affected by these planned actions amounts to less than 5% of total emissions in the Dublin region, and this highlighted the problem of how to affect CO_2 beyond their own remit of their own energy use. The results of the DREM will allow local authorities to effectively create evidence-based policies and actions which will affect CO_2 emissions county-wide, by using the local authority's powers in spatial planning, land-use, planning policy and public infrastructure.

At a local level, local authorities in Ireland have to meet a number of legal climate action obligations and targets, and the results of this work have already helped and will continue to help support the DLAs to meet these obligations by taking action on climate and meeting their policy requirements in areas such as:

- ➔ preparation of **County/City Development Plans**
- ➔ identification of **Strategic Energy Zones**
- ➔ assessment of **Decarbonising Zones**
- ➔ preparation of **climate mitigation plans**
- ➔ roll out of **low-carbon infrastructure** (district heating, electric vehicle (EV) charging, etc)

- ➔ **Carbon and energy assessment** of planning applications
- ➔ creation of EU Covenant of Mayors **Sustainable Energy and Climate Action Plans**

As a part of the masterplan process, Codema engaged and worked directly with the local authorities and key staff members in the planning department, through workshops and one-to-one meetings. This was done to ensure that the scenarios proposed are in line with future planning, and are integrated into planning policy practices going forward, including development plans, local area plans, and strategic development zones. Outputs and findings from the DREM have also been featured in a number of conferences and webinars, most noteworthy of which were the first Dublin Climate Action Week[6] and Ireland's first energy planning conference[7], which explored the important role that energy planning has in developing and implementing actions that will help achieve ambitious climate targets.

Legal Obligations and Policies

Policies and legal obligations have gone through a number of revisions during the project, these revisions reflect the EU and global commitment to join efforts to keep global temperature rise below 1.5℃, considering climate change as a global emergency of our times. This can be clearly seen in the European Union's renewed ambition through the adoption of the EU Green Deal; within this framework, a target is set of at least 55% reduction of greenhouse gas emissions by 2030 and a long-term vision to reaching climate neutrality in Europe in 2050. This calls for the highest possible ambition from all EU countries in setting their medium and long-term targets and will put EU states on a trajectory to meet their climate neutrality target by 2050. The 2050 EU climate neutrality targets not only aim to reduce emissions but also aim to involve citizens in climate action and 'just transition' policy.

Ireland must also play its part in contributing to efforts to reduce climate change. Through the Climate Action and Low Carbon Development (Amendment) Bill 2021, and the Programme for Government, Ireland is set to reduce emissions by 7% per annum from 2021 to 2030, which is approximately a 51% reduction by 2030 (relative to 2018). It should be noted that this is a very ambitious target for Ireland as it even exceeds the EU 2030 target of 55% reduction in emissions relative to 1990 levels. Furthermore, Ireland's national Climate Action Plan 2021 has established a net-zero GHG emission target for the country by 2050. The Climate Action Plan 2021 also advocates the need for a just transition and improving climate resilience of all communities and citizens. It also highlights the leadership role of the public sector, including local authorities, and the continued importance of citizen engagement and community leadership.

The role of spatial planning in addressing climate action is also addressed in the Climate Action Plan. It is stated that '*Better spatial planning will reduce the carbon emissions of new developments, and deliver a better quality of life, including shorter commute times, better connections between our places of work and homes, and more vibrant, people-focused environments.'* (Government of Ireland, 2021).

Furthermore, at a regional and local level, the Local Authority Climate Action Charter commits local authorities to several actions that will ensure that they play a key leadership role locally and nationally in delivering effective climate action. Among other commitments, all local authorities will advocate for climate action and put in place a process for carbon proofing major decisions and programmes, including investments in transport and energy infrastructure. The Charter also sets a new target for the public sector of 50% energy efficiency by 2030. Local authorities (LAs) must also ensure that they build local citizen engagement, which can be done through collaborations on climate action initiatives with local community groups, local enterprise and local schools and higher-level institutions. Through the charter, LAs have also committed to support employees to undertake changes in their lifestyles both at work and at home, to reduce carbon impact and encourage work-based employee-led groups to identify and implement ideas for improvement

Local level climate action has been highlighted in multiple policy and legislative documents. This can be clearly seen in the Climate Action Plan 2021, which highlights the leadership role of the public sectors, the importance of citizen engagement and community leadership to meet our mid- and long-term goals. The importance of a bottom-up

[6] https://dublinclimatechange.codema.ie/climate-action-week/
[7] http://www.codema.ie/media/news/recording-now-available-planning-our-energy-future/

approach to climate action and local governments can be also seen in the Programme for Government, which highlights the 'just transition' and the need to transition to a low-carbon future, while also emphasising the importance of empowering local governments and citizens in the role of climate action.

Furthermore, the Climate Action Plan 2019 asked LAs across Ireland to identify decarbonising zones (DZs) (Action 165) for their LA area, with the scope of reducing emissions in each zone by 7% per annum, which is approximately 51% emission reduction by 2030. This task has been carried through into the updated Climate Action Plan 2021. The Government recognises the key enabling role that local authorities have in advancing climate action at the local and community level. The development of DZs presents a real opportunity to showcase that LAs across Ireland can be best placed to lead and be exemplars in the area of local level climate action. This also gives them the chance to develop innovative carbon emission solutions, partner with local stakeholders, increase visibility of projects and engage the public on climate action.

The Regional Spatial and Economic Strategy (RSES) for the Eastern and Midland Region includes a number of climate action Regional Policy Objectives (RPOs) that directly link to the LAs and the pivotal role they have to help mitigate climate change at a local level. This is clearly showcased in RPO 7.35, which tasks LAs to identify Strategic Energy Zones (SEZs) as areas suitable for energy generation: *'EMRA shall, in conjunction with Local authorities in the Region, identify Strategic Energy Zones as areas suitable for larger energy generating projects, the role of community and micro energy production in urban and rural settings and the potential for renewable energy within industrial areas. The Strategic Energy Zones for the Region will ensure all environmental constraints are addressed in the analysis. A regional landscape strategy could be developed to support delivery of projects within the Strategic Energy Zones.'*

The RSES also acknowledges the need for evidence-based spatial planning in RPO 3.6, which states that '*City and county development plans shall undergo assessment of their impact on carbon reduction targets and shall include measures to monitor and review progress towards carbon reduction targets.'*

Achieving these ambitious goals and targets will require strong governance, robust and evidence-based policy at all levels with the need of a variety of funding supports, a just transition, technical advancements, exploration of co-benefits, societal innovation and ultimately – supporting each other in delivering climate action.

The Role of Energy Planning

The International Energy Agency has identified that "Cities should be at the heart of the energy transition" with cities accounting for two-thirds of all primary energy demand and 70% of total energy-related CO_2 emissions[8]. The EU identifies bottom-up approaches at a local and regional level as key to helping European countries meet national level CO_2 emission reduction targets. For example, the Covenant of Mayors for Climate and Energy[9] is an EU initiative which aims to accelerate the decarbonisation of municipality territories across Europe through implementation of local level energy action plans. The initiative has been very successful, with over 7,000 signatories (12 of which are Irish local authorities) and is backed by the EU Directorate General for Energy.

There is clearly an interest in local level energy planning in Ireland, but it is not widely carried out and there are no guidelines for local authorities. There is a knowledge gap within the local authorities around energy in general, and there are no qualified energy planners within the local authorities. In Ireland, local authorities have a lower level of autonomy when compared with other more experienced municipality regions around Europe, where in many countries local level energy planning is actually a legal requirement.

For example, under the Act on Municipal Energy Planning, all Swedish municipalities are required to carry out and implement an Energy Plan[10]. In 1979, the first Heat Supply Act was introduced in Denmark requiring municipalities to

[8] IEA (2016) *Energy Technology Perspectives 2016*
[9] https://www.covenantofmayors.eu/en/
[10] Wretling et al. (2017), *Strategic municipal energy planning in Sweden – Examining current energy planning practice and its influence on comprehensive planning,* Energy Policy Volume 113, p.688-700

create heat energy plans for their areas, giving them the power to engage in local heat planning, decision-making on energy infrastructure and resource prioritisation[11]. In Germany, all federal states have incorporated national level energy policy objectives into their planning roadmaps, and according to German law, renewables expansion and land use conflicts must be dealt with through municipal spatial planning practices[12]. One of the three key principles of Scotland's Energy Strategy is to create a *"smarter local energy model – enabling a smarter, more coordinated, approach to planning and meeting distinct local energy needs that will link with developments at the national scale"*[13].

All of these national level obligations and strategies recognise the vital role and impact of local level energy planning on national level targets. The advantages of implementing effective local level energy plans are clear; the most sustainable cities in Europe, like Stockholm, Copenhagen and Hamburg, have implemented city-wide energy plans, with clear pathways and long-term commitments to a low-carbon future. The implementation of these plans not only accelerates carbon reductions, but enhances the cities competitiveness, reputation, and quality of life.

Energy planning is built on evidence-based forward planning, which is essential to ensure that the local authority area, region and country has the required infrastructure in place to serve both new and existing developments with low-carbon and low-cost technologies. It can help bridge the gap between national policy and local implementation, while potentially also enabling multi-level governance. In Ireland, there is a great need to bridge the gap between energy and spatial planning. Furthermore, it is vital to consider holistic energy solutions that allow for the integration of different energy systems to allow for more cost-effective solutions, rather than having different solutions or technologies working in isolation. Planning, particularly for energy, is transboundary, and so analysing each local authority area in silos does not allow identification of the optimal solutions. Analysing the energy system of the whole Dublin region allows identification of cross-boundary solutions and cooperation opportunities between the Dublin municipalities.

Local energy planning also allows for greater local participation and benefits, which can help with improving citizen buy-in to the low-carbon transition. Local level energy planning is therefore key in helping local authority areas achieve 2030 and 2050 emission reduction targets.

Masterplan Overview

As explained previously, this masterplan focuses on the Dublin region; Dublin City, Dún Laoghaire-Rathdown, Fingal and South Dublin, and takes a holistic approach to energy modelling, which allows for better, more cost-effective solutions than looking at separate sectors in isolation. The main energy sectors identified by this masterplan are the heat, electricity and transport sectors. Figure 3 on the next page shows the flow and synergies between each energy sector, where energy efficiency in buildings impacts both the heat and electricity sector, whilst transport, namely electrification of the transport sector, would impact the electricity sector. Thus, a holistic approach to modelling energy demand is of utmost importance.

The analysis undertaken examines in-depth the local energy characteristics of the Dublin Region, taking account of such aspects as the building stock's efficiency and energy demand, the capacities of local electricity infrastructure, land-use constraints and availability, transport network capacities and vehicle use, and layered with expected population and development growth. It also examines the potential for local renewable and low-carbon generation of heat, electricity and renewable fuels in Dublin. It also models the interaction between sectors as shown in the figure on the next page.

[11] State of Green (2016) *District Energy: Energy Efficiency for Urban Areas,* part of Think Denmark series of White Papers for a green transition

[12] Mostegl et al. (2017) *Spatial energy planning in Germany: Between high ambitions and communal hesitations,* Landscape and Urban Planning, Volume 167, p. 451-462

[13] Scottish Energy Strategy (2017) *http://www.gov.scot/Topics/Business-Industry/Energy/energystrategy*

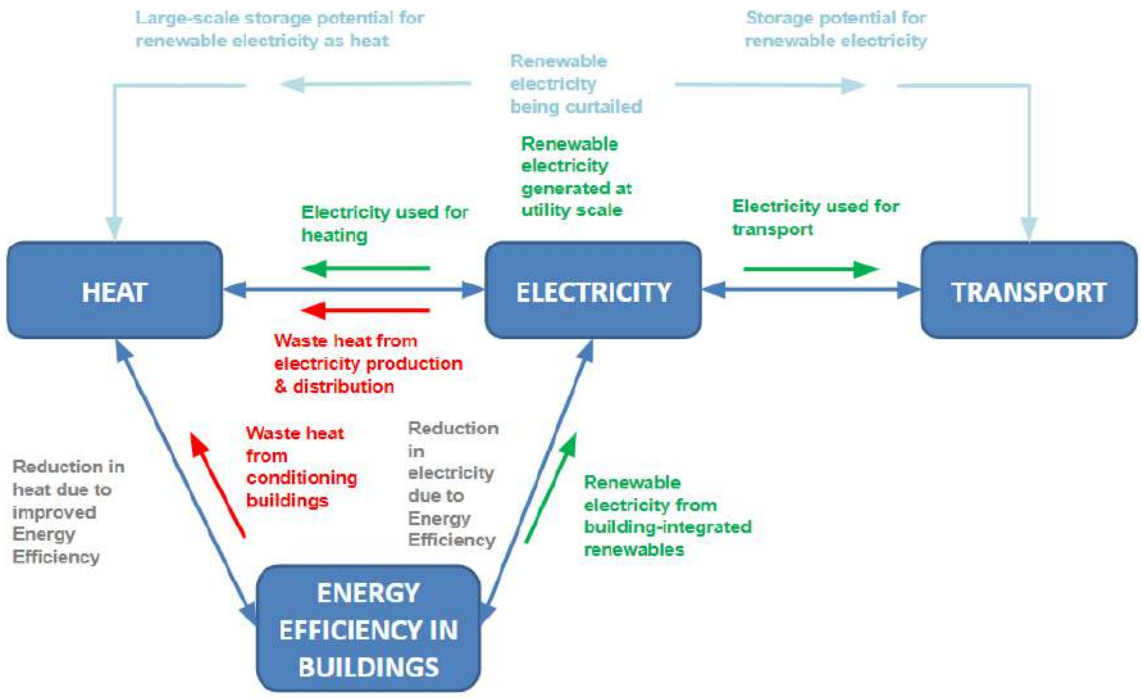

Figure 3: Energy Sector Interaction in the Dublin Region

DREM - Beyond State-of-the-Art

The Dublin Region Energy Masterplan is innovative and has gone well beyond best-practice in the energy planning process. This is particularly evident in the areas of energy modelling, evaluation and demonstration, which are described in further detail in the sections below.

Modelling

This project has modelled the energy sector (heat, transport and electricity) for the Dublin Region in great detail (down to individual building/street level in some cases). This level of detailed modelling has never been carried out for any area in Ireland previously, and for very few areas in Europe[14], and has allowed for a deeper understanding of the energy system of the country's most densely populated urban area. This project goes a step further by linking energy modelling outputs with spatial mapping. Typically, an energy model will look at a whole energy system in a holistic way and suggest scenarios to meet specific sectoral targets, but this does not identify specific areas where and how these changes are to be made. The DREM, on the other hand, makes use of detailed energy modelling, which is currently a very academically driven activity, and links it to spatial plans for real-life implementation. This is key, as it connects modelled scenarios directly with spatial planning and land use practices, which helps local and regional authorities in Ireland to shape energy use and emission reductions in their regions. Furthermore, it is common knowledge that low-carbon solutions are intrinsically linked to the spatial environment; for example, land or space needed for renewable energy infrastructure like wind and solar, additional areas required for active or public modes of transport like cycling or increased bus networks, the area's suitability for natural renewable energy resources such as geothermal or hydropower, or the potential to supply decentralised energy solutions like district heating.

Evaluation

Typically, local level energy plans are evaluated on a techno-economic basis only, with the evaluation criteria being lower carbon emissions. Technical feasibility evaluation outlines what is technically possible, but does not outline how or where this could be implemented or the effects of such changes on citizens/stakeholders directly affected. The DREM

[14] http://www.energyplan.eu/category/location/localenergyplan/

has evaluated the cost-optimal, spatially possible, technically feasible low-carbon scenarios for Dublin to meet its CO_2 reduction targets from the perspective of citizens, communities and the energy sector. This process was of utmost importance, as it ensured an overall positive outcome for all stakeholders affected by the changes proposed, and this process has also helped to reduce possible barriers to implementation. It was also a priority to evaluate the effects on all sectors as recommendations from this masterplan will be driven and implemented by the public sector.

The final low-carbon pathway set out in this report represents the lowest cost carbon reduction pathway for Dublin based on the analysis carried out by Codema. This pathway has also considered the real world technical constraints of adopting these technologies (e.g. environmental constraints, grid constraints, physical constraints, etc.). It also highlights the potential positive and negative impacts for society from an economic perspective, such as impacts on security of supply, indigenous resource use, employment, the environment, air quality and health. The pathway has also, importantly, considered the possible changes in the wider energy sector now and in the coming years (e.g. changes in the carbon intensity of electricity and gas, targets set at a national level, and likely cost reductions in certain technologies). Another unique and important aspect of the DREM is that it is an unbiased and impartial evaluation, created completely independently from any existing energy sector vested interests. In this pathway, the technologies with the lowest cost of carbon abatement in €/tCO_2 are prioritised in order to achieve the overall carbon reductions required for 2030 and 2050. Additional socio-economic factors such as employment and air quality have also been calculated and are included in the summary table in the pathway section of this report for consideration.

Collaboration

To produce such a detailed project that has real-life application, Codema has collaborated with a number of organisations and academic bodies. The purpose of this was to make useful data available for further research; an example of this is Codema's work with the National Residential Modelling Group that was set up to centralise residential energy data between research groups.

Throughout this masterplan project process, Codema has had meetings with a number of organisations to discuss the various energy sectors outlined in this document; of particular note were the meetings held with energy providers to discuss current and future constraints for energy networks in Dublin, and the NTA to discuss transport models and emissions. Also, as a part of the masterplan process, Codema engaged and worked directly with the local authorities' planning departments, energy system operators and infrastructure planners, through workshops and on-to-one meetings, to ensure that the scenarios proposed are in line with future planning and growth predictions, and are integrated into planning policy practices going forward. The common assumptions used across multiple sectors are discussed further in the Knowledge Base section of the report with sector-specific assumptions .

Demonstration

The DREM is not solely a research activity; it is a real-life application, and has been and will continue to be implemented and demonstrated by the Dublin Local Authorities. This is the first detailed plan to be developed for energy policy makers at a local level in Ireland. Codema will continue to work closely with regional and local authorities to ensure the DREM outputs are used and integrated into ongoing work and planning practices.

Typically, most local level energy plans are presented as static reports and can potentially isolate users who are not familiar with technical aspects of energy systems like local authority planners, who are the main target audience for local level energy masterplans. The DREM, as further described in **Modelling Tools** in the **Knowledge Base** chapter, is presented not just as a report, but also as an interactive web-based platform, which hosts resources and maps which allow for planners, architects, civil engineers and the general public to find answers to energy questions in their area and increase engagement within the area of local energy.

Codema has prioritised and made use of open-source software such as QGIS for all spatial analyses, open-source Python-based tools for energy models. The main aim of this was to ensure that the DREM can be interrogated by others and can facilitate replicability by other local areas and regions within Ireland.

Report Layout

This report outlines the **Current Situation** and provides the reader with information on the energy use and emissions from the different sectors, along with current technologies that are in use. It also provides details on gap-to-targets and emission reductions necessary to meet 2030 and 2050 targets.

Following on from the current situation, is the **Knowledge Base**, which introduces the model created for this project and the different software packages and programs that were made use of throughout this research. This section gives a brief summary on the methodologies used to determine the current energy and emissions, along with future predicted business as usual energy and emissions, followed by projecting future constraints and costs, to help understand the suitability of specific low-carbon technologies. This section also gives information and context on the different low-carbon technologies that have been investigated throughout this research, and identifies the potential low-carbon technologies that can be availed of in the Dublin Region. It should be noted that further detailed methodologies, assumptions and limitations that accompany this Knowledge Base section can be found in the Appendices.

The **Pathway** chapter summarises the results from the Knowledge Base and provides the reader with findings for each technology, grouped by sector. It includes the full energy and emission reduction potential, along with the cost effectiveness of decarbonisation, health impacts and economic improvements. This section also includes a number of maps showing the spatial distribution of different low-carbon technologies and the most suited areas for adoption.

The **Conclusion** marks the final section of the main report; it summarises the pathway results and discusses the direct impact that this project has in terms of long-term local level energy and climate change mitigation policy that will indirectly help to reduce CO_2 emissions in the county, engage the private sector in Dublin's energy transition, and increase competitiveness and quality of life. It also highlights the different use cases for this research and how this can be furthered to improve expertise in the region or local area.

The **Appendices,** at the end of the main report, include detailed information on all the energy sectors discussed in the main document. The Appendices include comprehensive methodologies for current and future business-as-usual energy demands and emissions, constraints and costs for low-carbon technologies, and detailed low-carbon potential for the building, heat, electricity and transport sectors. Also included in the appendices is a regional overview of the social and economic impacts of the low-carbon pathway that has been identified in this report. Included in this is information on air quality and pollution, impacts of energy efficiency, renewable energy and emission reduction on energy costs, estimated abatement cost for Ireland to remove emissions from the atmosphere and job creation.

The current situation

Total Emissions

Currently, Dublin's emissions account for 5,699 ktCO2, which equates to approximately 4.22 tonnes of CO_2 per person (for the sectors identified in the DREM report), and is slightly higher than the national average (national average is 4.20 tonnes of CO2eq per person[15]).

Heat accounts for the majority of emissions within the Dublin region at 46%, followed by transport at 28% and electricity at 26% (it should be noted that electricity includes lighting, pumps and fans, electricity emissions for heat is captured in heating emissions). When compared to national statistics produced by SEAI[16], energy related emissions for heat account for 40.8%, transport accounts for 33.8% and electricity accounts for 25.3%, and so it is evident that heat emissions for the Dublin region are higher than the national share. This might be attributed to the high building density in the region and an ageing housing stock, with 78% of the stock in Dublin having been built prior to the year 2000, which is higher than the national average (71%[17]). The biggest contributors to heating emissions in Dublin are industry, commercial businesses and services, and homes. Meanwhile, emissions from electricity have reduced over recent years as more renewable energy is used for electricity generation. As for transport emissions, the emission share for Dublin is slightly lower than the national share and this can be due to a number of factors, including higher density of developments requiring shorter distances to be travelled, as well as access to higher quality public transport and walking and cycling facilities than in the rest of Ireland**.**

The map on the next page shows small area emissions for the Dublin Region; this includes emissions from the residential, non-domestic (public sector, commercial and industrial buildings) and transport sectors,. It should be noted that emissions from power generation associated with supplying the electricity and heat demands in buildings are based on the national grid emission factors[18].

As can be seen from the map, the highest emissions pertain to areas in close proximity to Dublin City Centre, which is a reflection of the high level of transport activity, number of businesses and residential buildings in the area.

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[15] It should be noted that figures for 2021 were based on population projections (in lieu of updated Census population figures) and might not reflect the exact population for both the Dublin Region and Ireland.

[16] https://www.seai.ie/data-and-insights/seai-statistics/key-statistics/co2/#:~:text=In%202020%2C%20heat%20rose%20to,year%20from%202013%20to%202019.

[17] https://data.cso.ie/

[18] https://www.seai.ie/data-and-insights/seai-statistics/conversion-factors/

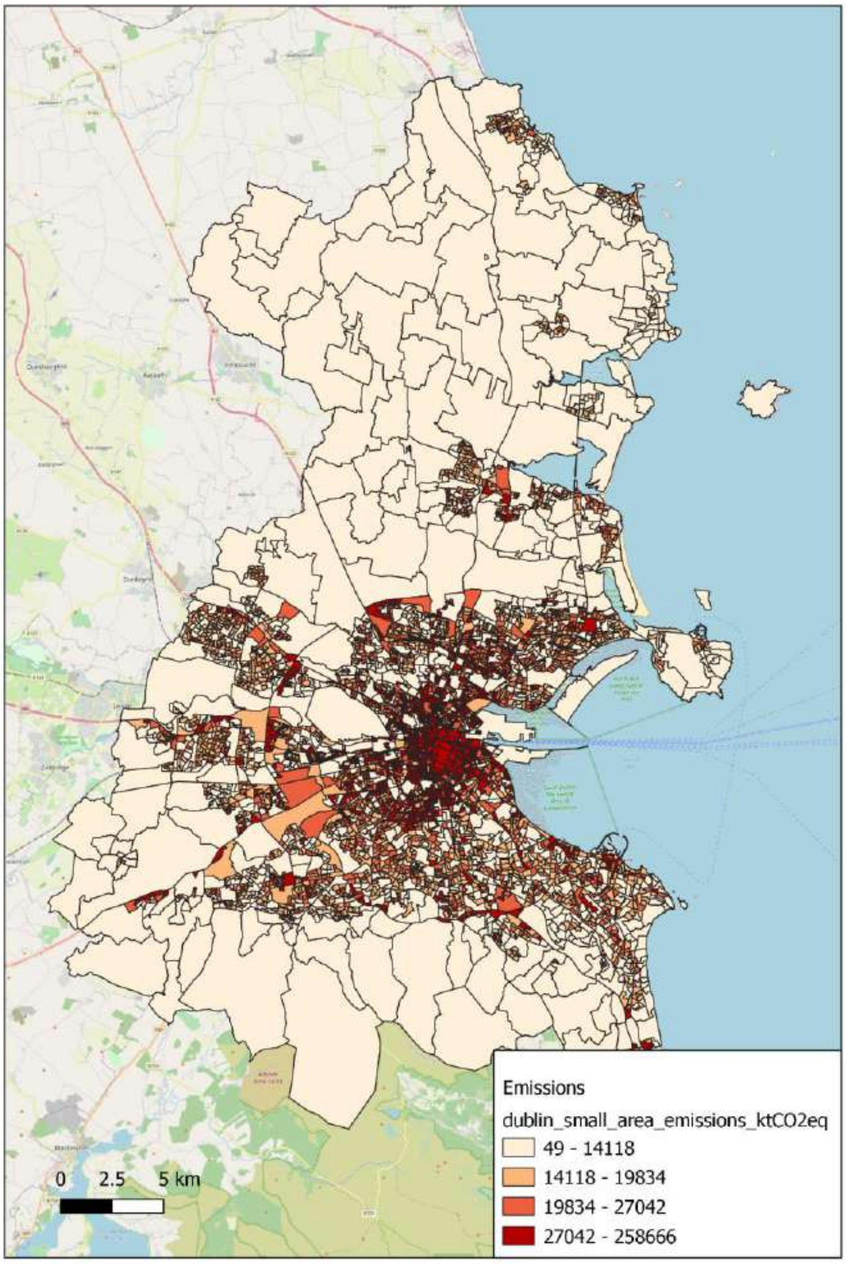

Figure 4: Total Dublin Region Emissions in $ktCO_2$/ km^2

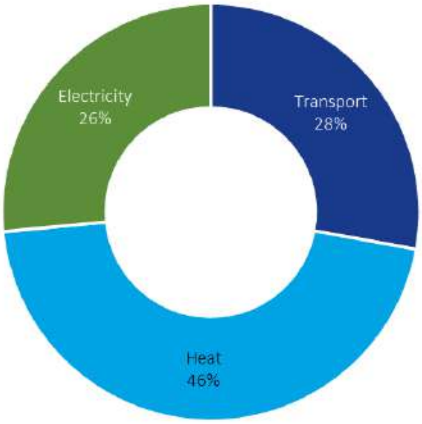

Figure 5: Share of Energy Related CO_2 by Sector

In 2021, the sectors that have the highest impact on emissions are the residential and transport sector, which combined, contribute around 57% to total emissions. These are closely followed by commercial buildings and services, data centres and industrial (non-ETS[19]) buildings, each amounting to 19%, 16% and 3% respectively. Finally the public sector - which includes all public buildings located in the Dublin Region, account for approximately 5% of total emissions.

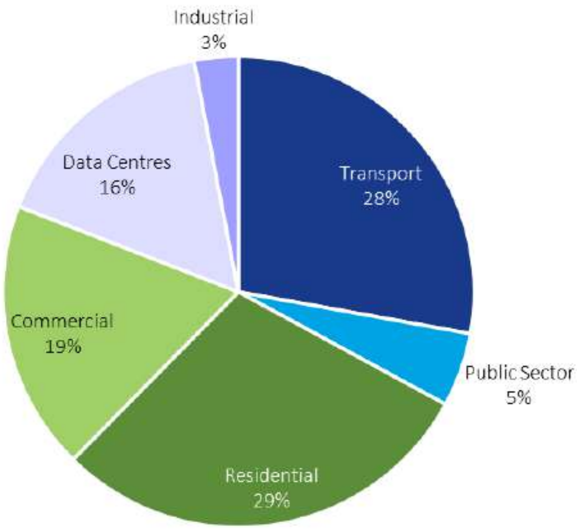

Figure 6: Dublin Region Annual Emissions

Gap to Targets for 2030 & 2050

Emissions for the period between 1990 and 2020 (shown in the graph on the next page) were estimated using national EPA[20] inventories, which date back to 1990 for Ireland. These figures were used as currently, there are no regional historical emission inventories that date back to 1990, thus national inventories were made use of and were scaled down based on population to the Dublin Region[21]. Figure 7 shows emissions for the Dublin region (scaled down from

[19] The EU Emissions Trading System is a "cap and trade" scheme where a limit (the cap) is placed on the right to emit specified pollutants over a geographic area and companies can trade emission rights within that area.
[20] https://www.epa.ie/our-services/monitoring--assessment/climate-change/ghg/
[21] It should be noted that these figures are only an estimated representation of Dublin GHG emissions.

the national EPA emission inventories and only includes emission sectors that have been identified in this masterplan) along with the 2021 emissions that have been produced by this masterplan.

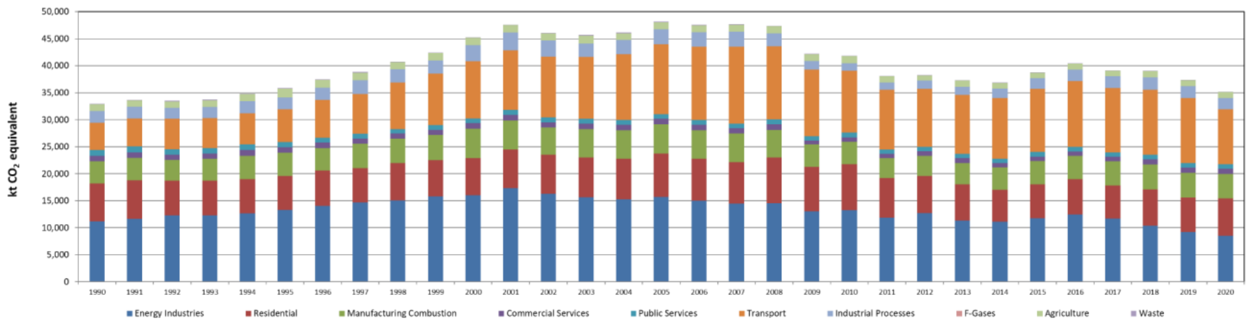

Figure 7: Provisional all Ireland GHG Emissions 1990-2020. Source: EPA [22]

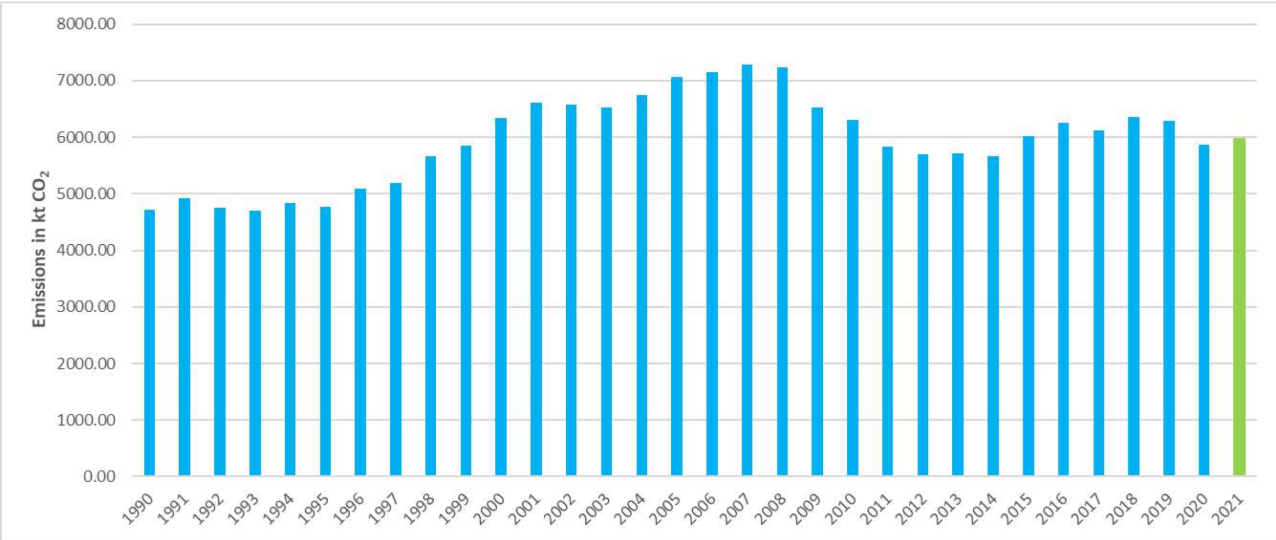

Figure 8: Dublin GHG Emissions 1990-2021

The gap-to-target (i.e. difference between the current emissions and the target emission levels) is shown in the figure on the next page, which depicts total emissions for the Dublin Region and the gap to 2030 and 2050 targets. Furthermore, sectors included in the chart only account for those that have been addressed in this Masterplan report, i.e. residential, commercial services, public services, transport and industrial processes. This allowed Codema to compare 2021 results from this project (2021 green coloured bar in the chart) to the EPA adjusted figures for Dublin. It should be noted that the provisional figures from the EPA's inventory includes the effect of Covid-19 for the year 2020. At a national level[23] it was found that Covid-19 restrictions helped decrease transport emissions by 15.7% while residential sectoral emissions increased by 9% in 2020. This overall decrease in emissions is reflected in Figure 8 for the Dublin region (which has been scaled down from the national EPA emission inventories). The 2021 emission estimates, produced from this masterplan project, do not account for Covid-19.

The figure includes Dublin's 2030 and 2050 target. The 2030 target (green shaded bar) corresponds to a 51% reduction from 2018 figures. This 51% reduction in emissions aligns with the Programme for Government[24], which states that Ireland is 'committed to an average 7% per annum reduction in overall greenhouse gas emissions from 2018 to 2030 (a 51% reduction over the decade) and to achieving net zero emissions by 2050'. This national average is an ambitious target for the Dublin Region to achieve, yet it aligns well with the European renewed ambition through the adoption of

22 https://www.epa.ie/publications/monitoring--assessment/climate-change/air-emissions/irelands-provisional-greenhouse-gas-emissions-1990-2020.php

23 https://www.epa.ie/publications/monitoring--assessment/climate-change/air-emissions/EPA-Provisional_GHG_Inventory_1990-2020_latest_trends_circulate.pdf

24 https://www.gov.ie/en/publication/7e05d-programme-for-government-our-shared-future/

the EU Green Deal. Within this framework, a target is set of at least 55% reduction of greenhouse gas emissions by 2030 and a long-term vision to reach climate neutrality in Europe in 2050.

Currently, Dublin's total emissions account for 5,969 $ktCO_2$, meaning that the current gap to the 2030 target amounts to approximately 2,856 $ktCO_2$ (48% reduction in emissions needed to meet the 2030 target). Furthermore, a reduction of 5,969 $ktCO_2$ will be needed to meet the 2050 net-zero target.

Net-zero emissions refers to the balance between the amount of GHG emissions produced and the amount of emissions that are removed from the atmosphere. Reaching net zero emissions means that the amount of GHGs added are not more than those being removed. This means that some GHGs are still released, but the remaining emissions would be removed/offset from the atmosphere through carbon sinks, such as forestry, wetlands, grasslands, etc. For this masterplan, the aim is to reduce energy related emissions as much as possible and set a pathway for Dublin to decarbonise the region that aligns with the Programme for Government decarbonisation target of 51% reduction by 2030 and puts Dublin on a trajectory to achieve net zero emissions by 2050.

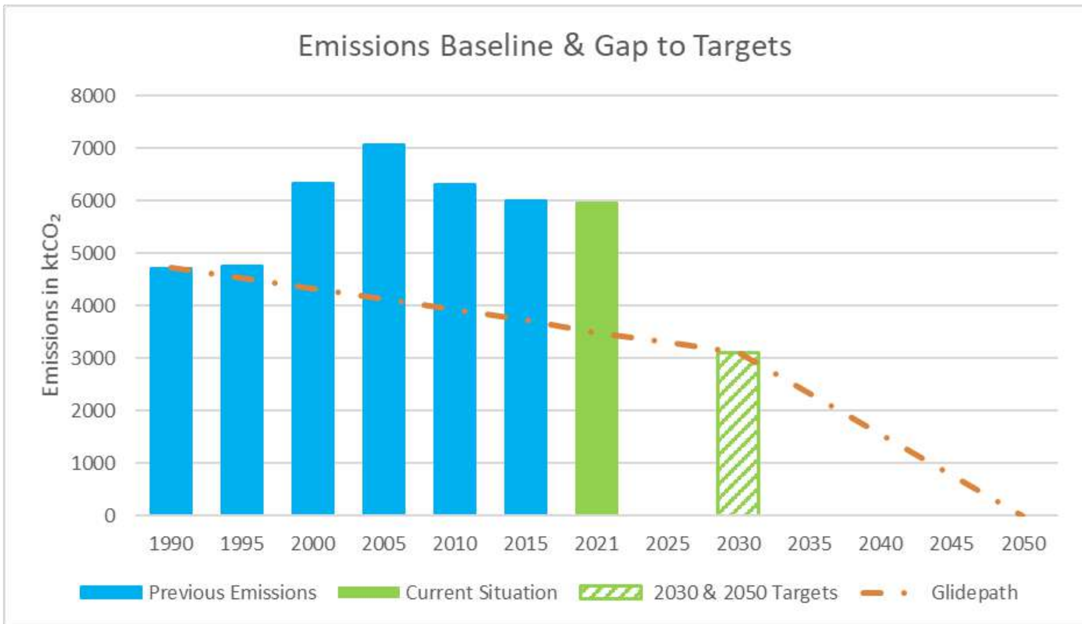

Figure 9: Dublin Baseline Emissions Inventory and Gap to 2030/2050 Targets

Electricity

The current electricity demand in Dublin has been split into two main areas: residential demand and commercial demand. Residential electricity demand has been mapped below. The darker regions in the commercial electricity demand map which denote higher demand map tend to be focused around areas with large industrial sites such as data centres.

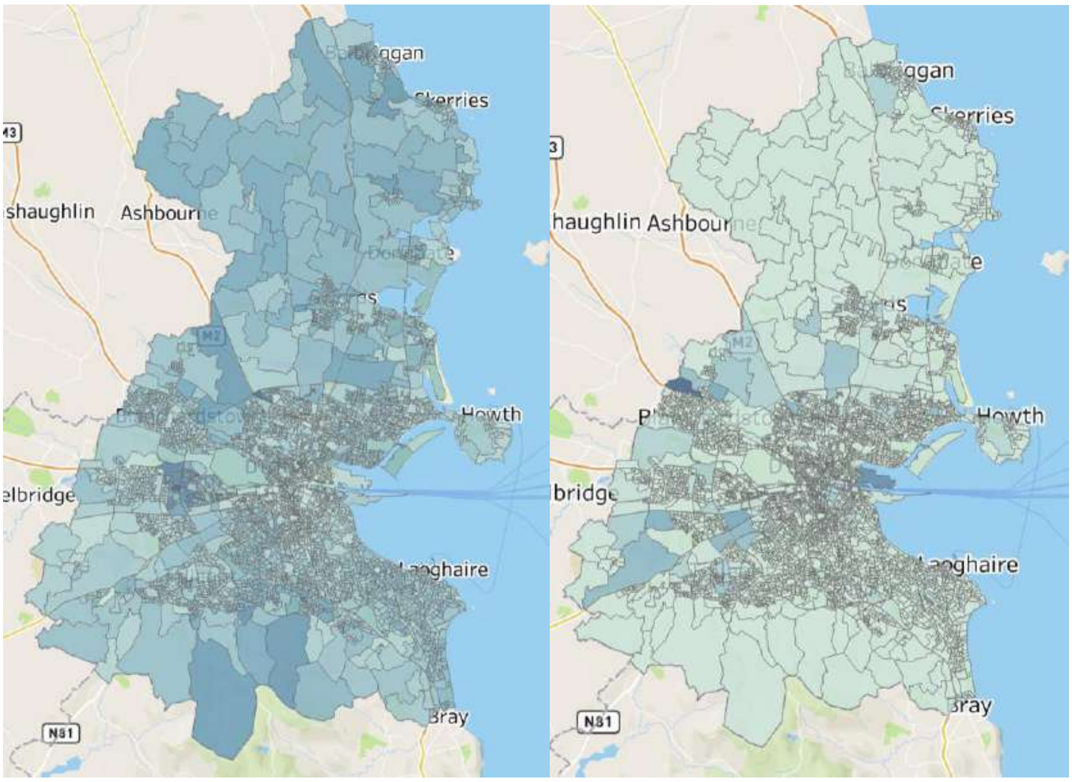

Figure 10: Residential (left hand side) and commercial (right hand side) electricity demand maps for Dublin

The breakdown of current electricity demand in Dublin is set out in the table below. This shows that x represents the biggest electricity consumer in Dublin. It should be noted that the electricity demand in buildings does not include consumption for all domestic appliances in the buildings due to lack of information on this particular area. As a result the annual demand in residential buildings may be larger than what is outlined below.

Table 1: Breakdown of electricity demand by sector

Sector	Electricity Demand (MWh)
Public Sector	559,000
Residential	2,944,268
Commercial	1,349,260
Industrial	300,000
Data Centres	4,310,000
Total	**9,462,528**

The existing grid has been modelled and the remaining load that can be accomodate without upgrades has been mapped as shown in the figure below. This has been used to spatially differentiate the cost of grid upgrades for future technologies such as heat pumps and EVs.

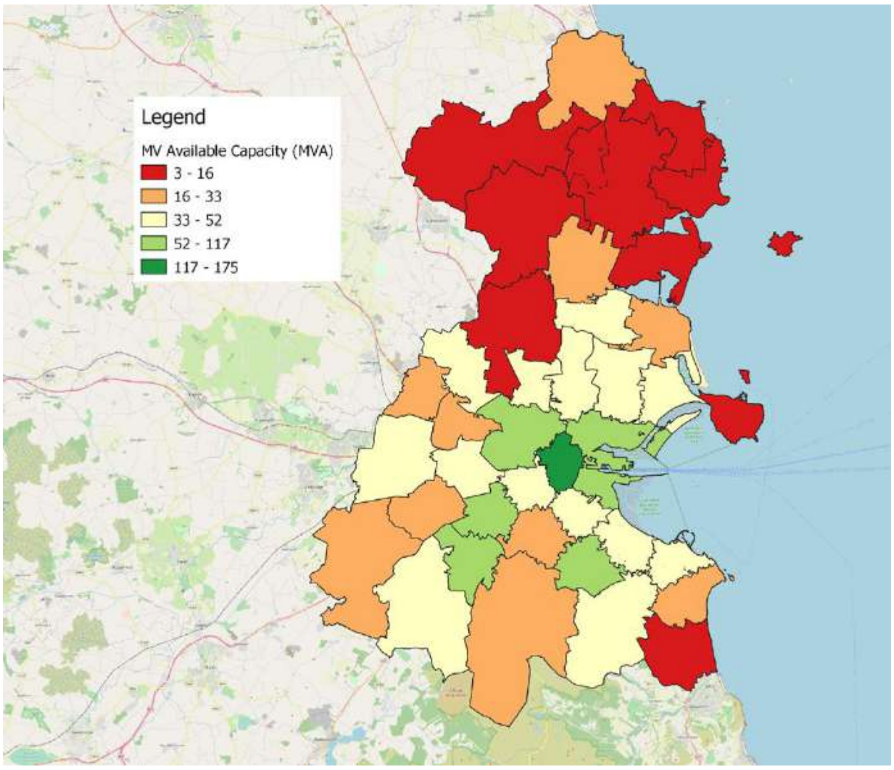

Figure 11: Available medium voltage electrical substation capacity (MVA) map

Heat

The heat demand for Dublin has been calculated for each small area in the county. The map below shows the heat demand density for the Dublin City region. This and further interactive heat demand maps for all local authority areas can be found on Codema's online map portal here[25].

[25] https://codema-dev.github.io/map/district-heating-viability-map-v2/

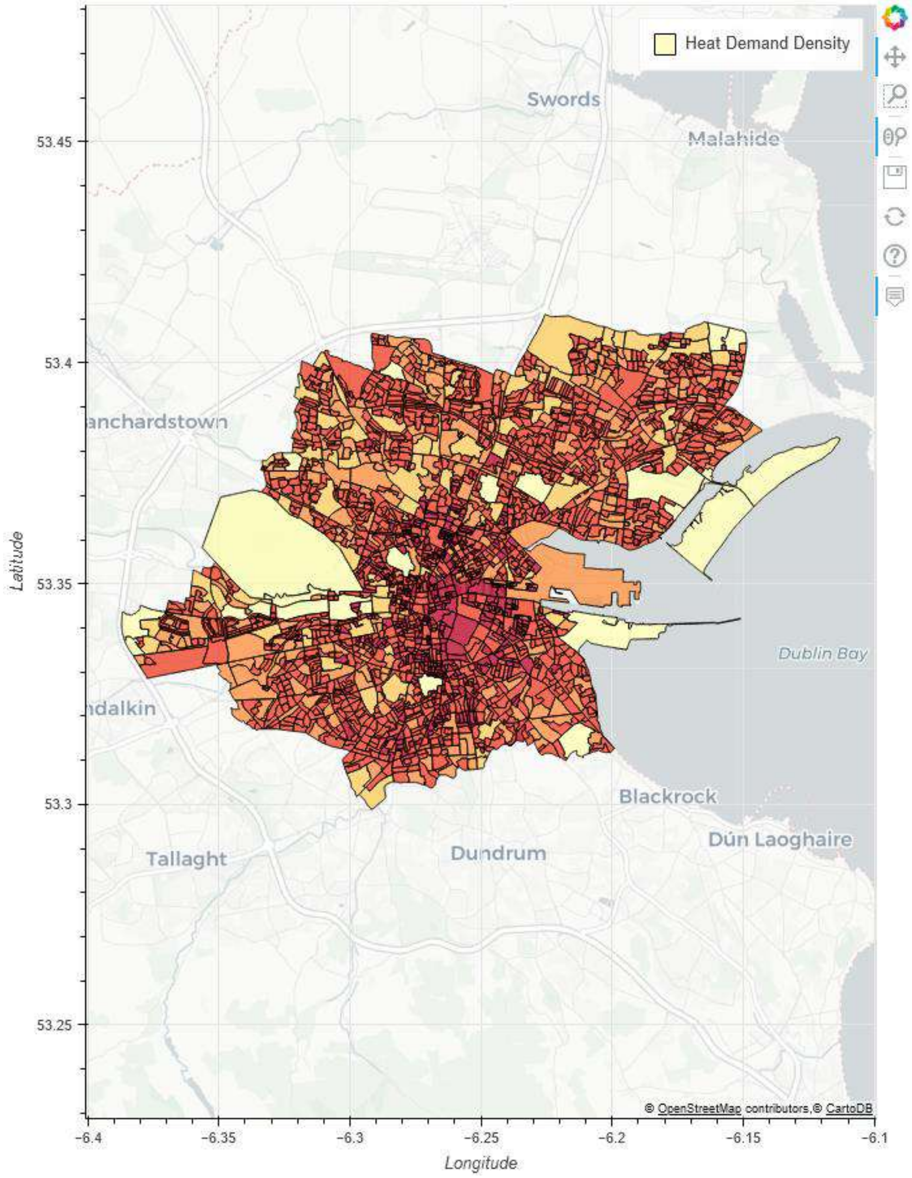

Figure 12 : Example heat demand density map showing Dublin City (interactive heat demand density maps for all local authority areas in dublin available in the codema online map repository[26])

The heating fuel mix is different for every small area and this has been mapped by Codema. This heating system breakdown map is available on Codema's online map portal here[27]. The graph on the next page provides a breakdown of heating systems by local authority area and for the county as a whole. This graph shows that gas is the main heating fuel in Dublin followed by direct electric and oil.

[26] https://codema-dev.github.io/map/district-heating-viability-map-v2/
[27] https://codema-dev.github.io/map/boiler-maps/

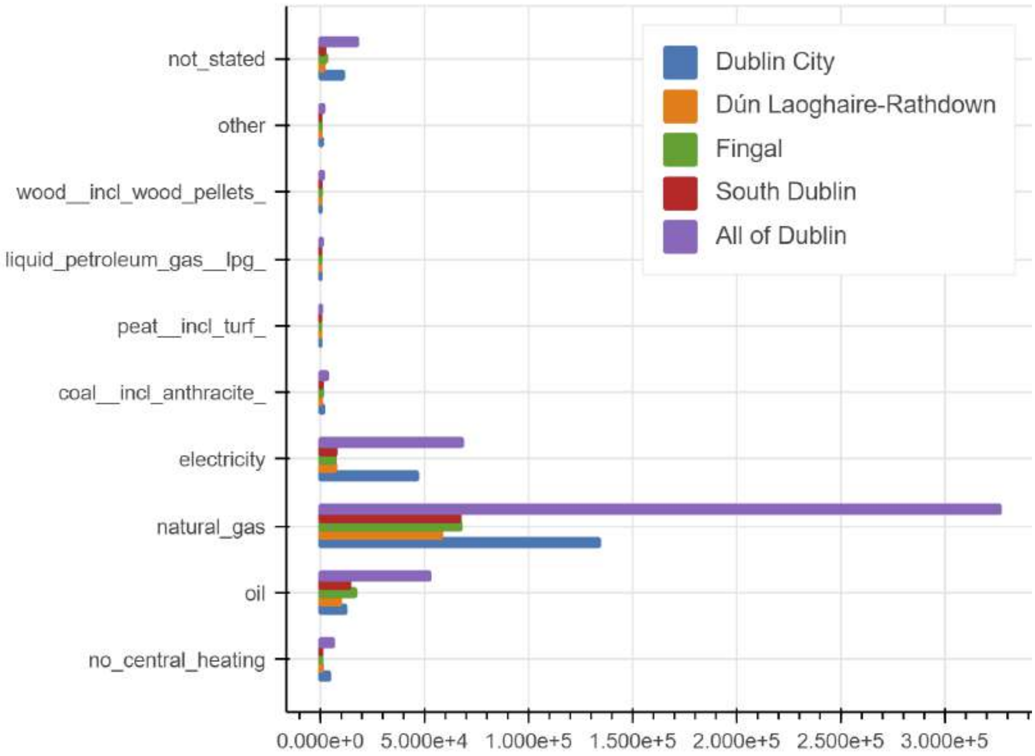

Figure 13: Breakdown of current heating technologies in Dublin

The map below shows the proportion of homes that are currently considered heat pump ready. Heat pump ready homes are considered to have a heat loss indicator of less than 2. The heat loss index is a measure of how quickly the heat leaks from the building. This in turn affects the size and efficiency of the heat pump. From the map below we can see that the majority of dwellings in Dublin do not have the necessary heat loss efficiency to be deemed suitable for adopting heat pumps (areas coloured in light green) and would require building fabric upgrades to make them suitable.

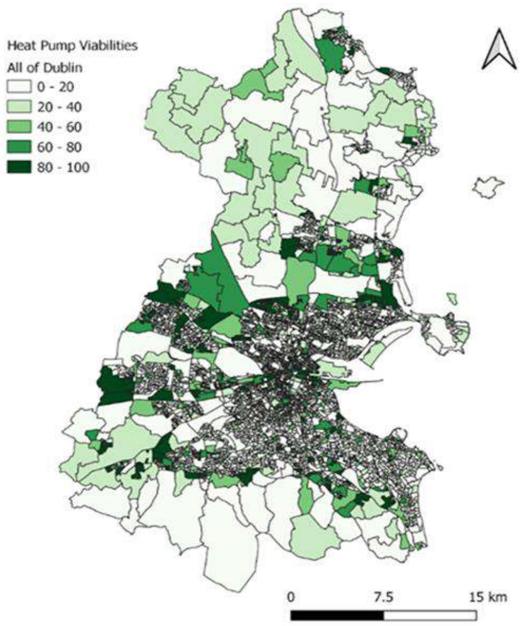

Figure 14: Heat pump viability map of Dublin

The average BER for Dublin is D2. The map below shows the average BER for residential dwellings in each small area in the county.

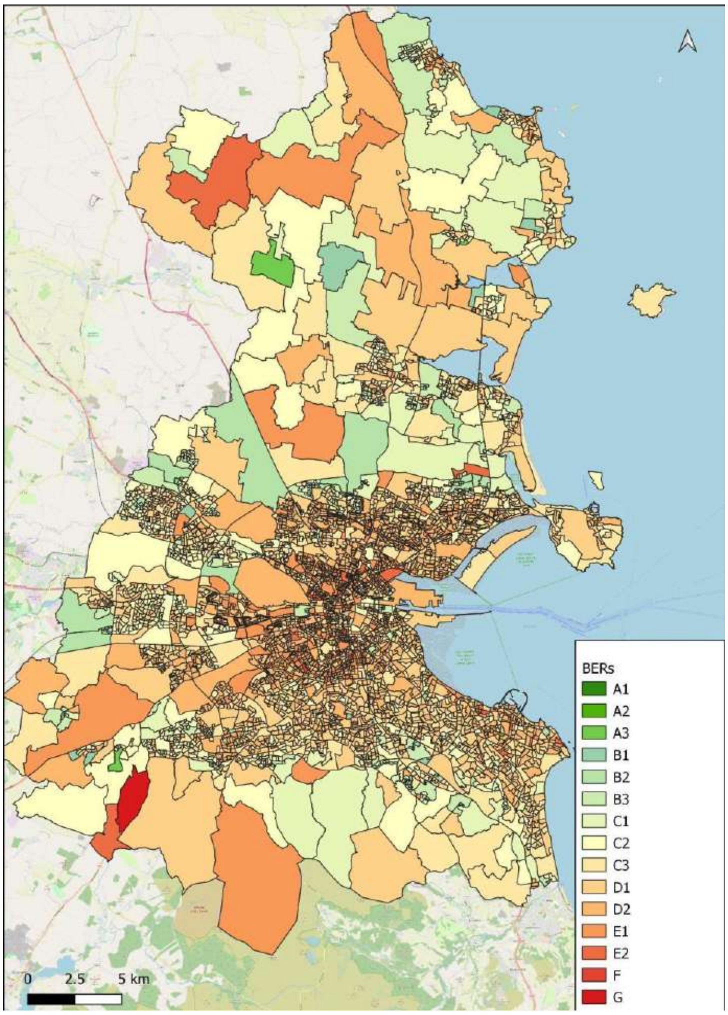

Figure 15: BER by Small Area for the Dublin Region

Transport

Current energy demand relating to the Transport sector is presented in the chart below. Cars dominate the picture, accounting for just under two thirds (65%) of transport energy demand in Dublin. Heavy goods vehicles (HGVs) are next at 15%, followed by light goods vehicles (LGVs) at 12%. Public transport, consisting of bus, light rail and heavy rail services account for approximately 7%, while rail freight barely registers at all, at just 0.01% of the total.

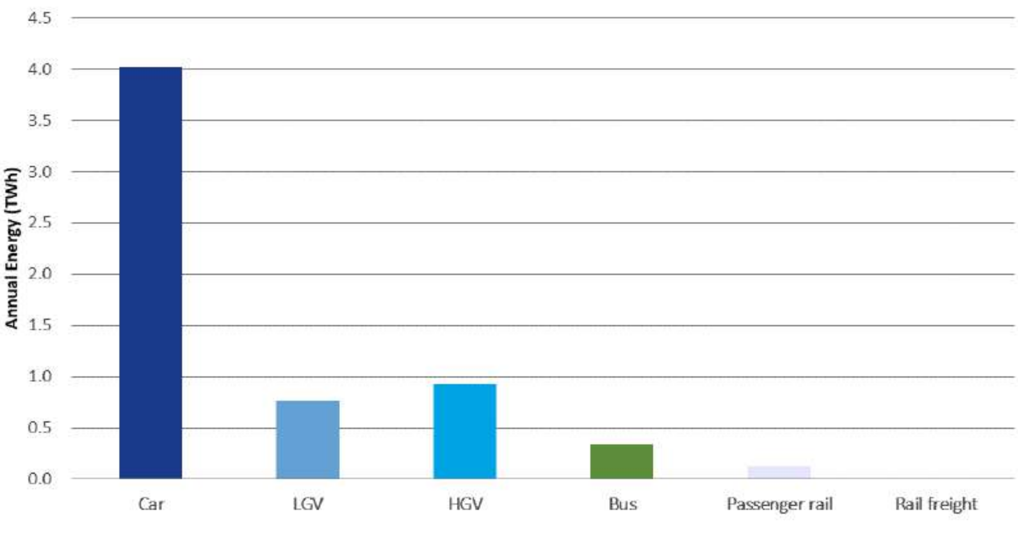

Figure 16: Annual energy demand by vehicle type in Dublin

In terms of GHG emissions, the proportion attributable to each vehicle type corresponds closely to that for energy above. Road transport accounts for 98% of transport emissions in Dublin. The map below displays the annual emissions intensity on Dublin's roads in terms of tonnes of CO_2 per kilometre of road.[28] The roads with the highest traffic volumes, and therefore highest CO_2 emissions, can clearly be identified, such as the M50 ring road and the main radial national roads and motorways into the city.

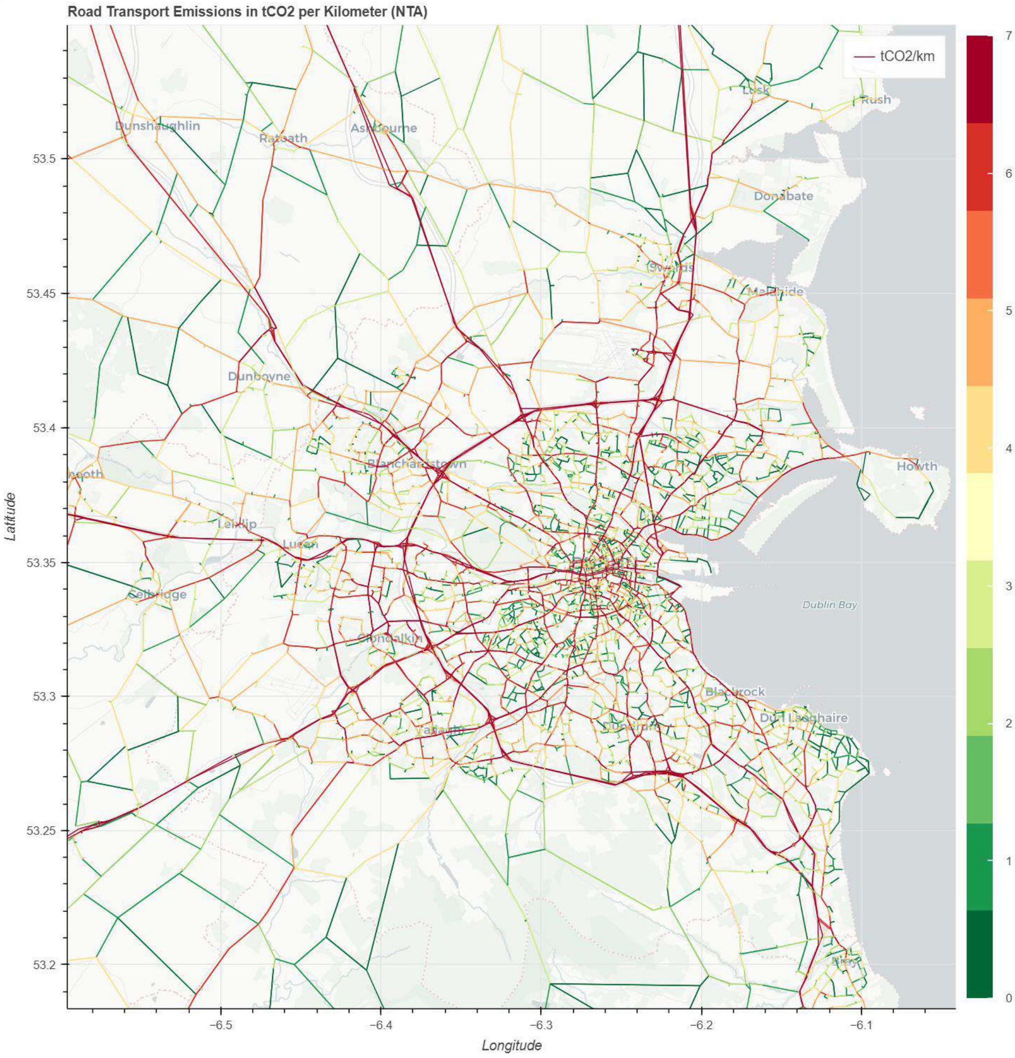

Figure 17: Current road transport emissions intensity by link

As of December 2020, there were 554,470 private cars licensed in Dublin. This represents just over 25% of the total number of cars licensed in the country. The number of cars licensed in Dublin has grown rapidly over the past number of decades. Between the years 2006 and 2020, the number of cars in Dublin increased by 18%, or over 83,000 vehicles.[29] Of those vehicles licensed in Dublin in 2020, 5,257 were battery electric vehicles (BEVs), representing just under 1% of the vehicle stock.[30] Figure 18 below shows the number of cars per 1,000 adults in Dublin by small area, according to the 2016 Census.[31] It can be seen that in certain parts of the county, car dependency is extremely high, with up to four out of every five adults having their own cars. This value tends to drop the closer you get to the city centre, where space for car storage is more limited and better public transport and active travel links are available.

[28] Based on data provided from the NTA's East Regional Model, see "Knowledge Base" for details

[29] CSO Transport Omnibus 2006, Department of Transport Irish Bulletin of Driver and Vehicle Statistics 2020

[30] Department of Transport Irish Bulletin of Driver and Vehicle Statistics 2020

[31] https://codema-dev.github.io/map/cars-per-thousand/

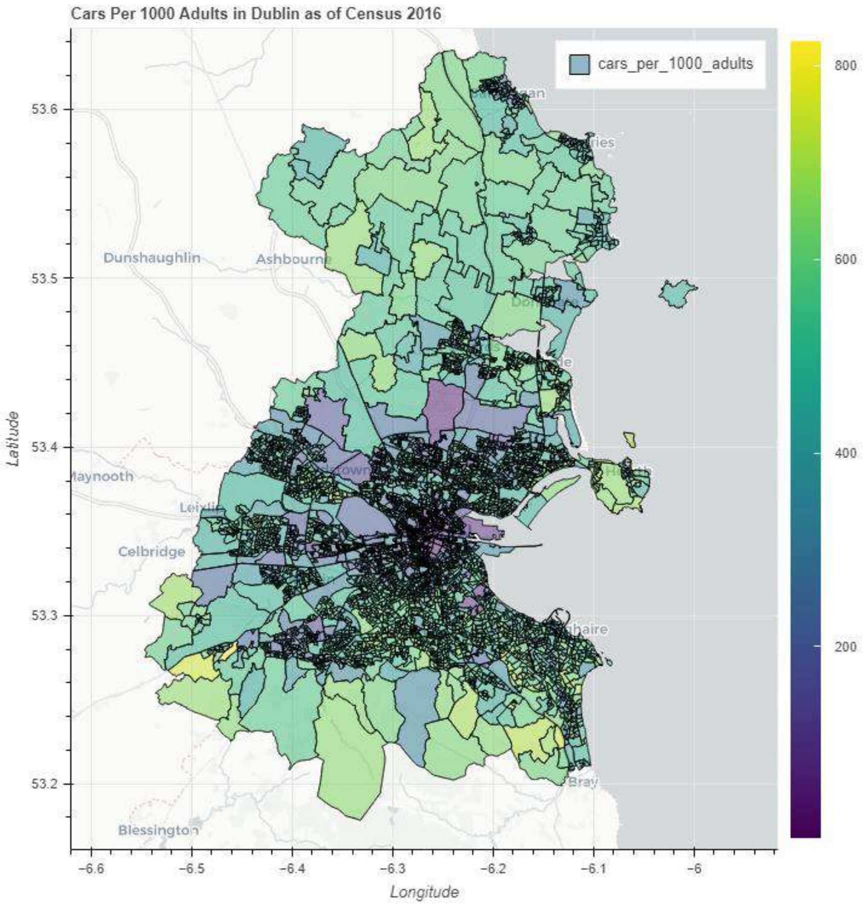

Figure 18: Number of cars per 1,000 adults in Dublin

Provisional figures suggest that a further 43,756 cars were registered in Dublin in 2021.[32] Almost 10% of these new registrations were BEVs, while a further 9% were plug-in hybrid vehicles (PHEVs). It is clear that the trend towards BEV and PHEV cars in Dublin is rapidly accelerating, as demonstrated in the chart on the next page. In parallel with this growth, the number of public electric vehicle charge points (EVCPs) has also been increasing. As of late 2020, there were approximately 170 public EVCPs in Dublin, the majority of which were 22 kW rapid chargers, with a further 10% consisting of 50 kW rapid chargers. According to recent analysis carried out on behalf of the four Dublin Local Authorities, approximately 3,700 public chargers may be required in Dublin by 2030.[33]

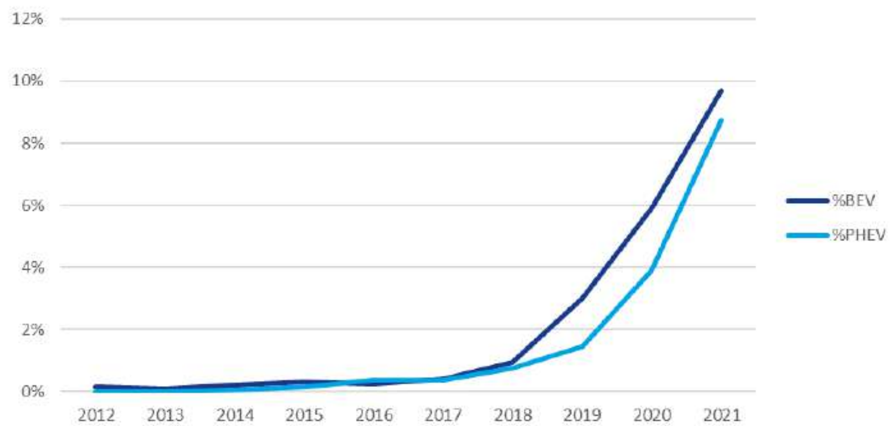

Figure 19: Annual percentage share of new BEV and PHEV car registrations in Dublin over the past decade

[32] https://stats.beepbeep.ie/

[33] Dublin Local Authority EV Charging Strategy, December 2020

In 2020, there were 78,226 goods vehicles licensed in Dublin. Approximately 49,000 of these were LGVs, while the remaining 29,000 were HGVs. As of the end of 2020, 1,139 urban buses operated within the Dublin Metropolitan Area (DMA), made up of the Dublin Bus and GoAhead fleets.[34] Passenger rail in Dublin consists of the two Luas electric light rail lines, the electric DART heavy rail line and a number of diesel commuter and intercity heavy rail services. Rail freight consists of two services serving Dublin Port, with connections to Tara Mines and Ballina, respectively.

It is important to note also the avoided energy consumption and GHG emissions through active travel (i.e. walking, scooting, rolling and cycling). Figure 20 below presents the modal split for personal transportation in Dublin, as a percentage of the total number of journeys taken.[35] It can be seen here that walking and cycling combined make up 21% of the total number of trips in Dublin. The 3% figure for cycling falls far short of the 10% overall national target set out in the Government's Smarter Travel policy document for 2020.[36] This is particularly disappointing given how suitable Dublin is for cycling, and compares extremely poorly against similarly sized European cities, some of which achieve up to 30% of all trips carried out by bicycle.[37]

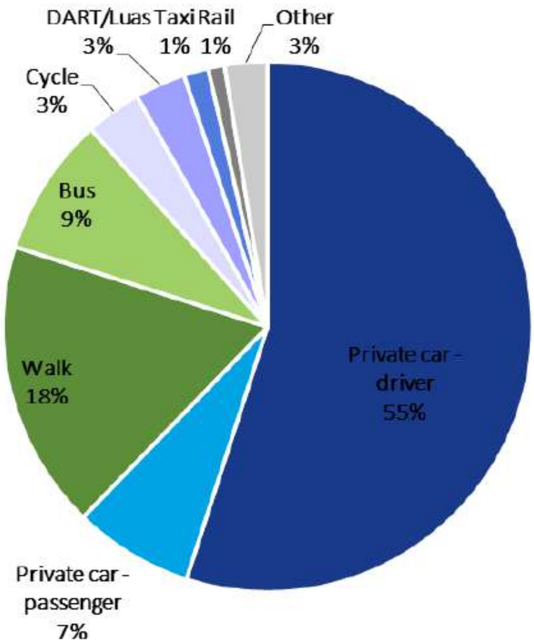

Figure 20: Percentage distribution of journeys by mode of travel for Dublin (CSO National Travel Survey 2019)

The Bike Life Report, published in 2019, estimated that 70.5 million cycle trips were carried out annually in the DMA, adding up to a total distance travelled of 375 million km.[38] This is equivalent to the distance travelled by approximately 28,000 cars in a year. This report also found that safety is the single largest barrier to having more people cycling in Dublin. The existing cycle network in Dublin is of overall poor quality, with little segregation or protection from vehicular traffic, and minimal consideration at junctions. In 2013, the NTA developed the Greater Dublin Area Cycle Network Plan, shown on the next page, which aimed to develop a complete network of primary, secondary and local feeder routes in Dublin, as well as direct links to surrounding towns outside of the county. Progress on developing this network has been particularly slow, however, as the map of Dublin's network in 2021 beneath this clearly shows. The Bike Life Report found that Dublin's residents recognise the many benefits of active travel, with 84% of DMA residents surveyed supporting the creation of new protected on-road cycle routes, even if this meant a reduction in road space for other traffic. However, even now, many new cycle schemes being proposed in Dublin are fundamentally compromised by the perceived requirement to maintain existing motor traffic flows. This approach ignores the proven concept of 'traffic

[34] https://www.nationaltransport.ie/wp-content/uploads/2021/11/NTA-GDA-Transport-Strategy-2022-42-15.11.21-FA-WEB-1.pdf

[35] https://www.cso.ie/en/releasesandpublications/ep/p-nts/nationaltravelsurvey2019/howwetravelled/

[36] https://assets.gov.ie/19854/37d829c9748446349ff586045bfbcaba.pdf

[37] https://civitas.eu/resources/civitas-policy-note-smart-choices-for-cities-cycling-in-the-city

[38] https://www.sustrans.org.uk/bike-life/bike-life-dublin-metropolitan-area

evaporation', whereby over time, traffic does not simply divert to nearby streets as a result of traffic management measures, but actually disappears or 'evaporates' due to people changing their behaviour.[39]

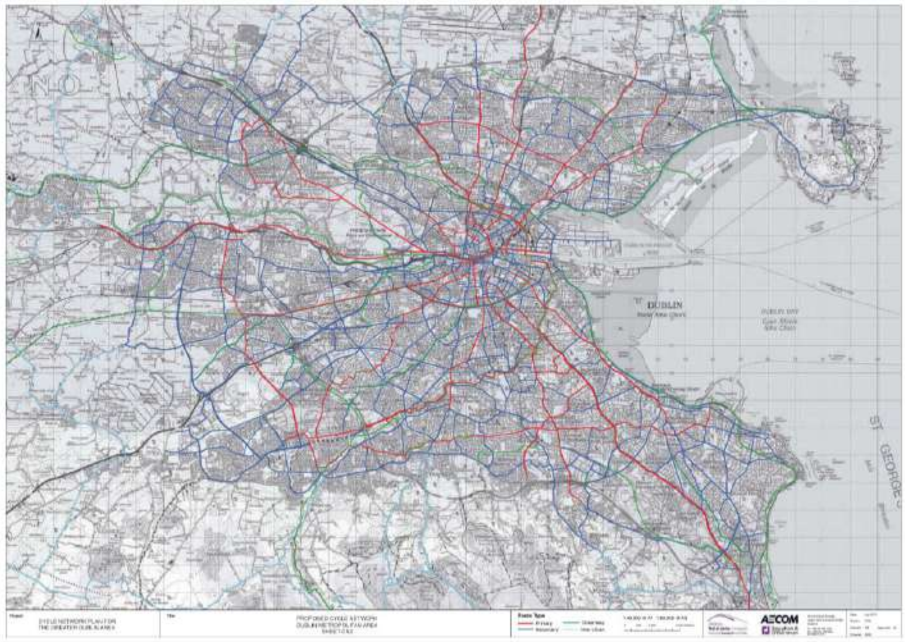

Figure 21: NTA Greater Dublin Area Cycle Network Plan[40]

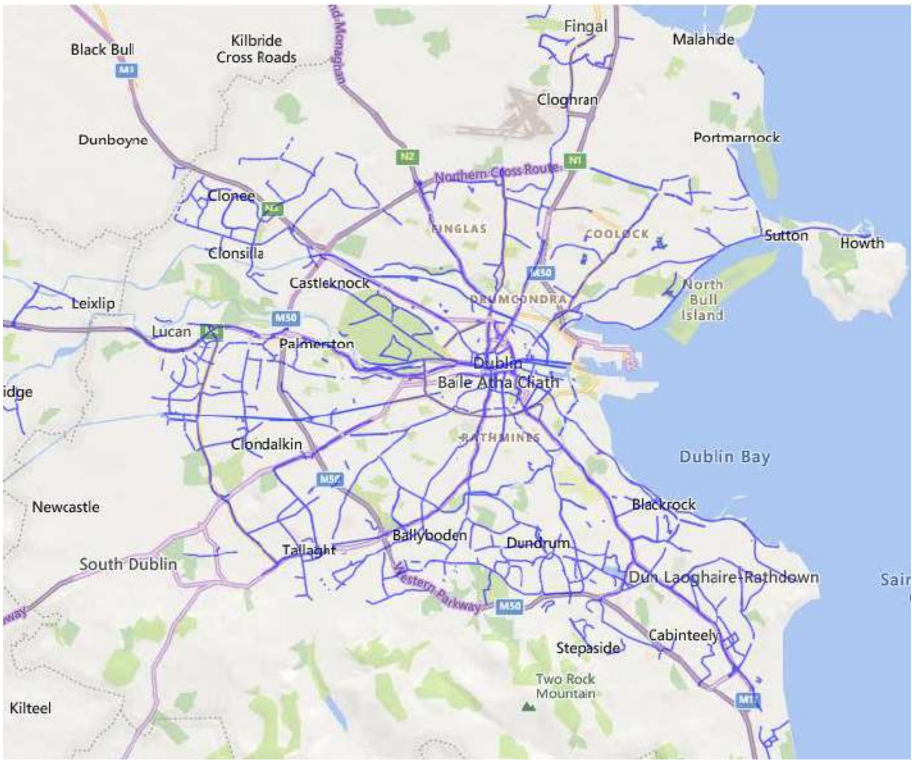

Figure 22: Cycle network in Dublin in 2021[41]

Since the start of the Covid-19 pandemic, and boosted by the effect of having a Green Party Minister for Transport for the past two years, much more emphasis has been placed on realising the potential societal benefits that active travel

[39] https://www.engineersireland.ie/LinkClick.aspx?fileticket=DipUgQJl2Es%3D&portalid=0&resourceView=1
[40] https://www.nationaltransport.ie/planning-and-investment/transport-investment/greater-dublin-area-cycle-network-plan/
[41] https://data.smartdublin.ie/dataset/greater-dublin-area-cycle-infrastructure-nta

brings. This increased emphasis, combined with a €360 million annual national budget for active travel, has allowed the Dublin Local Authorities to set up their own internal active travel teams tasked with developing safe, segregated and attractive infrastructure and targeting significantly increased active travel uptake. Already we are seeing the fruits of this process, with interim analysis of DLR's Covid Mobility Works at Blackrock Village showing that traffic evaporation is occurring where road space has been reallocated away from private motor vehicles to active travel and the public realm.[42]

[42] https://www.tudublin.ie/media/website/news/2021/main-news/TU-Dublin--DLR-COVID-19-Mobility-Review-FINAL-RESIZED.pdf

Knowledge Base

This chapter introduces the modelling tools used and the energy model that was created for this project. This section summarises methodologies used to determine the current energy and emissions, along with future predicted energy and emissions, and future constraints and cost projections, to help the reader understand the suitability of specific low carbon technologies. It also gives information and context on the different low-carbon technologies that have been investigated throughout this research, and identifies the potential low-carbon technologies that can be made use of in the Dublin Region. It should be noted that further detailed methodologies, assumptions and limitations that accompany this Knowledge Base section can be found in the Appendix Section.

Energy Modelling

As a part of this project process, Codema has prioritised the use of open-source tools in the development of the Dublin energy models. The main motivation for this was to help ensure that the report is interactive and open for use and interrogation by others in order to facilitate a high degree of replicability by other regions within the country. With the main aim being that this masterplan can provide support to further decarbonisation in the near future through evidence-led energy planning and policy making.

Resources and maps are readily available online on Codema's Github[43] and Tableau Public[44], which allow the general public to find answers to energy related queries specific to their area, which can help increase engagement with citizens on local level energy planning and climate action. Making useful data available (with some pre-processing completed) was a starting point for this project, which could help further research by wider organisations and academic bodies. This has been the case with Codema's collaboration with the National Residential Energy Modelling Group; over multiple discussions in this modelling group, it was agreed to standardise the process of cleaning residential data and that it would be made available for wider use.

Building Energy Model

It should be noted that this is a very new space in energy research in Ireland. Codema's energy planning team found that existing open-source tools are either not designed for Ireland or are only designed to work at an individual building level. In the case of individual building models, it was necessary to bend reality to fit the tool by creating a handful of detailed individual building models and extrapolating these to fit the building stock. The main aim of the building energy model was to create a tool capable of modelling different buildings and their energy demands. Furthermore, it was also required that the building model should capture the energy and carbon savings from the energy retrofit of hundreds of thousands of residential buildings, whilst also having the ability to assess the Building Energy Rating (BER) improvement and the cost of each energy retrofit.

As a part of this project, multiple building energy model software was considered in great detail before Codema generated its own building model[45]. For the purposes of this project a new, simple building stock model was created for the Irish building stock to model hundreds of thousands of individual buildings all at once. This is discussed in further detail in **Appendix A – Energy Modelling.**

Residential Synthetic Building Stock

A synthetic residential building stock was created for the DREM; the purpose of this is to generate a complete energy dataset for the housing stock. The synthetic building stock for the residential sector is based on two main data sources, the Central Statistics Office's (CSO) 2016 census and SEAI's Building Energy Rating (BER) Research Tool.

[43] https://codema-dev.github.io/
[44] https://public.tableau.com/app/profile/rowan.molony https://public.tableau.com/app/profile/oisin.doherty
[45] https://github.com/codema-dev/rc-building-model

The BER Research Tool, developed by SEAI, was used in this analysis for the calculation of energy required for normal use of space heating, hot water, ventilation and lighting per metre squared area of a residential unit. The final energy rating given to a household is in kWh/m^2/year and an energy efficiency scale from A to G. It also provides an insight into other data, such as type of household, year of construction, location, floor area and fuel use.

The census is a mandatory survey of all dwellings and is a complete dataset of the residential housing stock, it includes location, period built and type of dwelling which is broken down into apartments, terraced, semi-detached and detached. However, this dataset is missing information on specific building characteristics (dimensions, insulation, efficiency of heating systems, etc.), whereas the BER Research Tool contains this information, but is not available for all Dublin dwellings. This occurs because buildings only require a BER if they are for sale or have been sold since 2009, if they are for rent, or the owner is applying for or has applied for grant funding for energy efficiency renovation.

To generate a complete synthetic residential building stock for all of Dublin with characteristics relevant for modelling energy demand and emissions, the census data was replaced with BER building characteristics. Buildings in the BER dataset are linked to the Census by matching two parameters common to each dataset which have the largest impact on predicted energy demand; building period and dwelling type. Buildings that do not yet have a certified BER were assumed to be typical or archetypal buildings. In order to create these typical buildings, it was assumed that buildings located close to one another and built during the same time period also have the same building properties. This synthetic building stock gave Codema a complete spatial analysis for building stock energy demand for cases where little or no building level data is available. Thus, the energy demand for the residential sector, broken down into heat and electricity, could be estimated.

As this procedure is somewhat complicated to implement, a web application named the Irish Building Stock Generator (IBSG)[46] was developed by Codema to automate the creation of a synthetic building stock to enable the wider Irish energy research community to reproduce the DREM building stock, and use it in their own research.

Non-Domestic Buildings

The non-domestic sector includes commercial, public and industrial buildings. The main data source for the non-domestic sector is a detailed list of all rateable commercial buildings, which was provided by the Valuation Office. This data includes a list of all the commercial properties, their location and respective floor areas in the Dublin Region. These properties were also broken down into different categories and types of use.

The non-domestic building sector is the most difficult sector to estimate building energy demand due to the lack of data available to develop a more robust methodology. The lack of data in this sector is not specific to Ireland, and provides a challenge which all EU member states will need to overcome. Work on analysing energy use in the sector is ongoing and significant advances in the collection and analysis of data have been made in recent years to improve the understanding of the profile of the commercial sector, energy use and energy saving opportunities. Thus, to estimate energy demands from non-domestic buildings, a number of different methodologies were used (this is explained in greater detail in **Appendix B – Building Sector Methodology**).

The model makes use of both metered data and theoretical energy demand. For the public sector, metered data was used since public sector bodies are required to report on their annual energy use and performance to the Sustainable Energy Authority of Ireland (SEAI). This is done through the Monitoring and Reporting system (M&R), which is used to track the public sector's progress towards their energy efficiency and emissions targets compared to the baseline year. The energy use for the different public sector bodies is reported in terms of building location, use and metered electricity and gas demands. For industrial buildings, when site-specific annual energy demand data was available on the Environmental Protection Agency (EPA) website through Annual Environmental Reports (AER), these were made use of. The AERs are used to provide a concise summary of licensees' environmental performance, some of the information captured in the AER include the companies' environmental objectives and targets achieved, goals to maintain compliance and summary results from emissions monitoring which includes energy demands (in kWh) broken

[46] https://github.com/rdmolony/ibsg

down by fuel used. Energy consumption benchmarks from the Chartered Institution of Building Services Engineers (CIBSE) were used for both commercial buildings and industrial (when AER reports were not available).

Modelling Building Heat and Electricity

Residential space and water heating demands are estimated from the synthetic building stock which, as explained previously, combines the census 2016 (which also gathers the household heating sources by small area) and the BER database (which estimates both space and water heating demands for the different dwelling types by period built in each small area). To estimate the energy consumption used for heating in the non-domestic sector, it was assumed that for public buildings', all GPRN metered data contributed to heating, whilst for industrial and commercial buildings, that all fossil fuel energy was used for heating.

To generate heat demands it was assumed that the Dwelling Energy Assessment Procedure (DEAP) model of hot water and space heat demand is indicative of actual usage. In order to determine the emissions associated with heat, the following typical heating system efficiencies were used for each heat source used, as shown in the table below.

Table 2: Heat Source Efficiency

Heat Source	Efficiency
Gas	85%
Oil (Kerosene)	80%
Direct Elec	100%
HP	300%
Wood Pellet Boiler	65%
Stove (soft wood)	65%
Stove (wet wood)	65%
Smokeless Coal	30%
Briquettes	30%
DH	460%

Electricity demands for the residential sector were estimated from the synthetic building stock, which included electricity demands from the BER database; this accounted for space and water heating (where relevant), pumps, fans and lighting. Whilst electricity demand for the non-domestic sector was estimated from MPRN metered data for the public sector, metered data from AER reports and benchmark electricity figures for the industrial and commercial sector.

Smart meter trial[47] data was provided by the Commission for Regulation of Utilities (CRU), this gave information about consumers' electricity usage behaviours (for both the residential and non-residential sector) and has helped to model demands and different times of the day. This was initially used to estimate diversified peak demands until better information in the form of the ESB special load reading data became available. Whilst this diversity curve was replaced in this analysis, it may still be useful for those looking at determining diversified peak electrical demands for equipment serving sites with fewer dwellings[48] and hence has been included in Figure 23 on the next page.

[47] https://github.com/codema-dev/cer-smart-meter-trials-2009-2011

[48] https://github.com/codema-dev/cer-smart-meter-trials-2009-2011

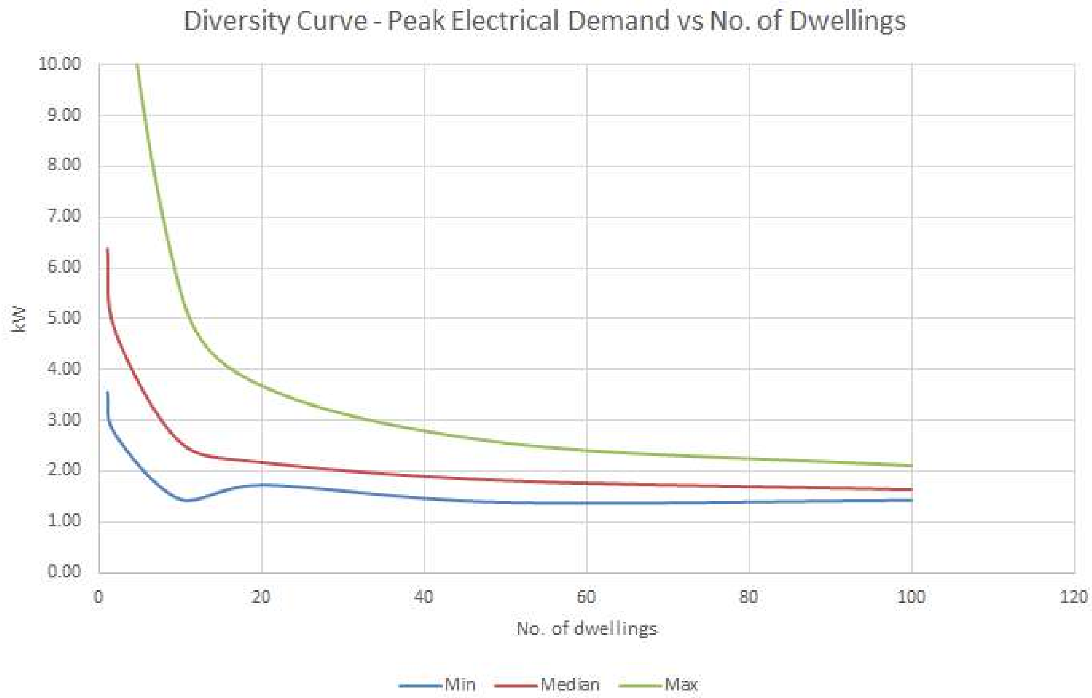

Figure 23: Residential electricity demand diversity curve

Modelling Building Retrofits and Carbon Savings

The level of building stock and energy demand information at such spatial resolution allowed for the identification of feasible building fabric upgrades for all buildings. Since building fabric information for non-domestic buildings was very limited, non-domestic building fabric upgrades were not considered. However, improvements in non-residential buildings' energy efficiency due to fabric upgrades (% improvement in energy efficiency) and improvement in heating technologies for this sector are accounted for in the Heat Section and it was assumed that commercial buildings in each small area would have a similar heating technologies as this for the most common residential dwelling in the small area (this is described in further detail in **Appendix C - Heat Sector Methodology**).

In order to improve energy efficiency and reduce emissions from the building sector, the residential building energy model was setup in such a way that it can model the impact that building fabric upgrades have on:

- BER ratings
- Heat Pump Viability
- Energy Savings
- Cost by Measure

The model makes use of current buildings' fabric U-values. U-values measure the effectiveness of a material as an insulator, meaning it determines a material's rate of heat loss. The well insulated material will have a low U-value and thus, will lose less heat. The building stock's U-values for walls, roofs and windows determine how much heat is lost through the building fabric. In order to retrofit a building to be able to meet a minimum B2 BER, it is necessary to first reduce its fabric and ventilation heat loss by retrofitting it. Detailed information on costs and the methodology used to derive building fabric costs can be found in **Appendix B - Building Sector Methodology**.

Buildings

The Current Building Stock

To decarbonise residential and non-domestic buildings in the Dublin region, it is essential to understand the current building stock. Detailed information on the region's energy efficiency in buildings and methodology can be found in **Appendix B - Building Sector Methodology.**

Residential Buildings

Dublin Region is predominantly made up of terraced (36%) and semi-detached (36%) dwellings. These were closely followed by apartments (22%) and the least common type of housing in Dublin are detached houses, making up 6% of the total residential building stock. The housing stock is an ageing and poorly rated building stock, with 78% of the stock having been built prior to the year 2000, which is higher than the national average (71% of the housing stock built prior the year 2000[49]).

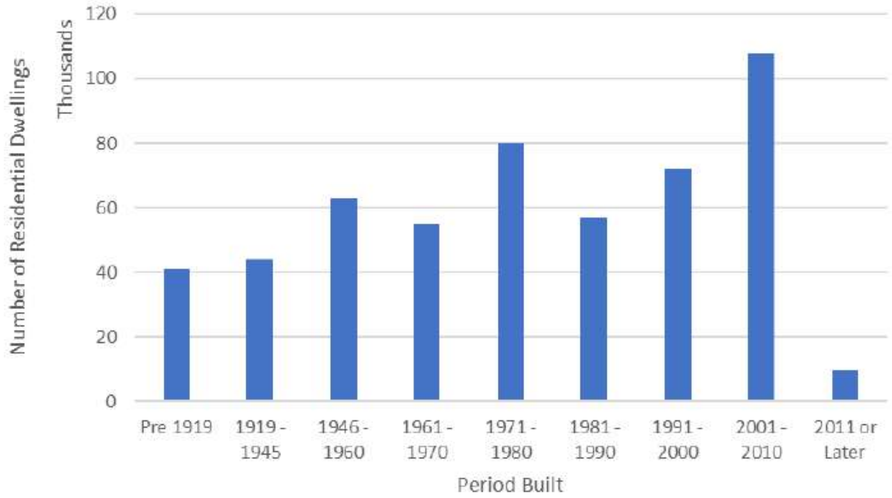

Figure 24: Period Built for the Residential Housing Stock in Dublin

Since the housing stock is an ageing stock, this affects the energy efficiency of the dwellings and as can be seen in the figure below, it reflects in poor BERs for the Dublin Region. As explained in the **Energy Modelling** Section**,** Codema generated the synthetic residential building stock for all of Dublin's residential buildings, and thus all residential buildings in Dublin were assigned a BER, which can be seen in the figure below. In Dublin the most common BER was found to be a D2 rating (17%) for the year 2021. Buildings rated D1 or worse made up 58% of the housing stock, whereas A and B rated buildings made up 12% of the stock. A map showing the BERs for each small area can be found in **Current Situation** or on Codema's Tableau website[50].

[49] https://data.cso.ie/
[50] https://public.tableau.com/app/profile/oisin.doherty/viz/DublinSmallAreaBER/Sheet1

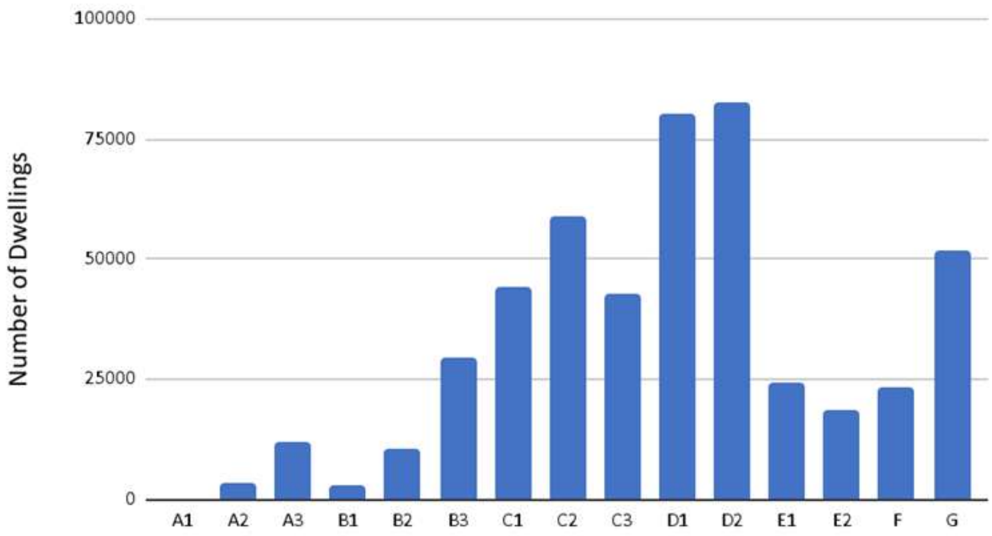

Figure 25: Dublin Region's Residential BERs

The total energy demand in the residential sector accounted for 10,407 GWh in 2021 in the Dublin Region, of which 80% is heat demand and the remainder (20%) is electricity demand.

Residential heating fuel sources (from 2016 census) mainly include natural gas, electricity, oil, coal peat, LPG and wood. The predominant heating source for the Dublin Region is natural gas, as it makes up a total of 68% of all households. This was followed by electricity at 14% and oil at 11%. Meanwhile, the combined remainder (coal, peat, LPG, wood, other sources, no central heating and not stated) only contributed 7% to residential heating sources.

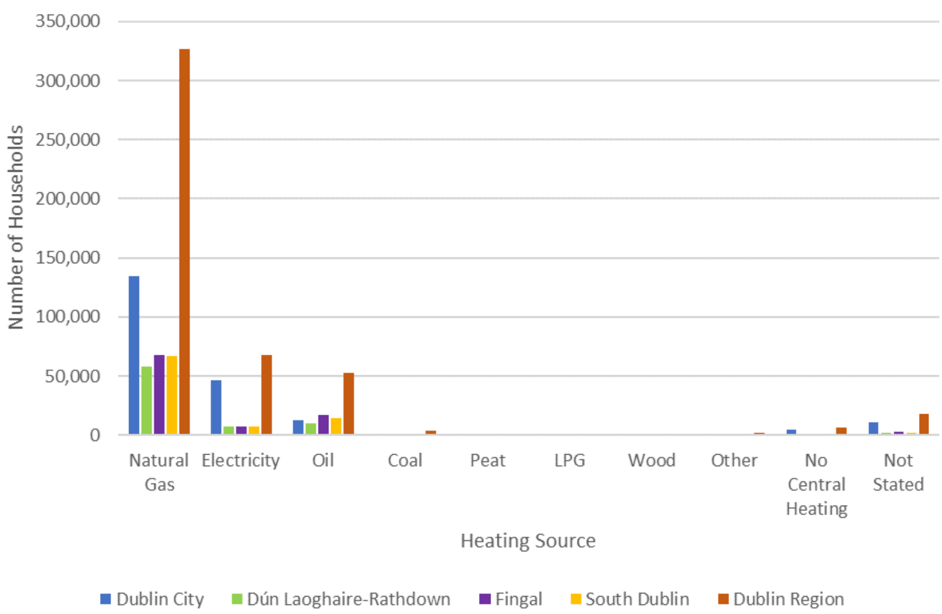

Figure 26: Residential Heating Sources

The residential sector is heavily reliant on natural gas for space and water heating, whilst electricity in the Dublin Region (accounting for 14% of the total) is mainly used for lighting, pumps and fans. The figure on the next page depicts total emissions from the residential sector by small area. Total emissions for this sector account for 1,758 $ktCO_2$ for the year 2021.

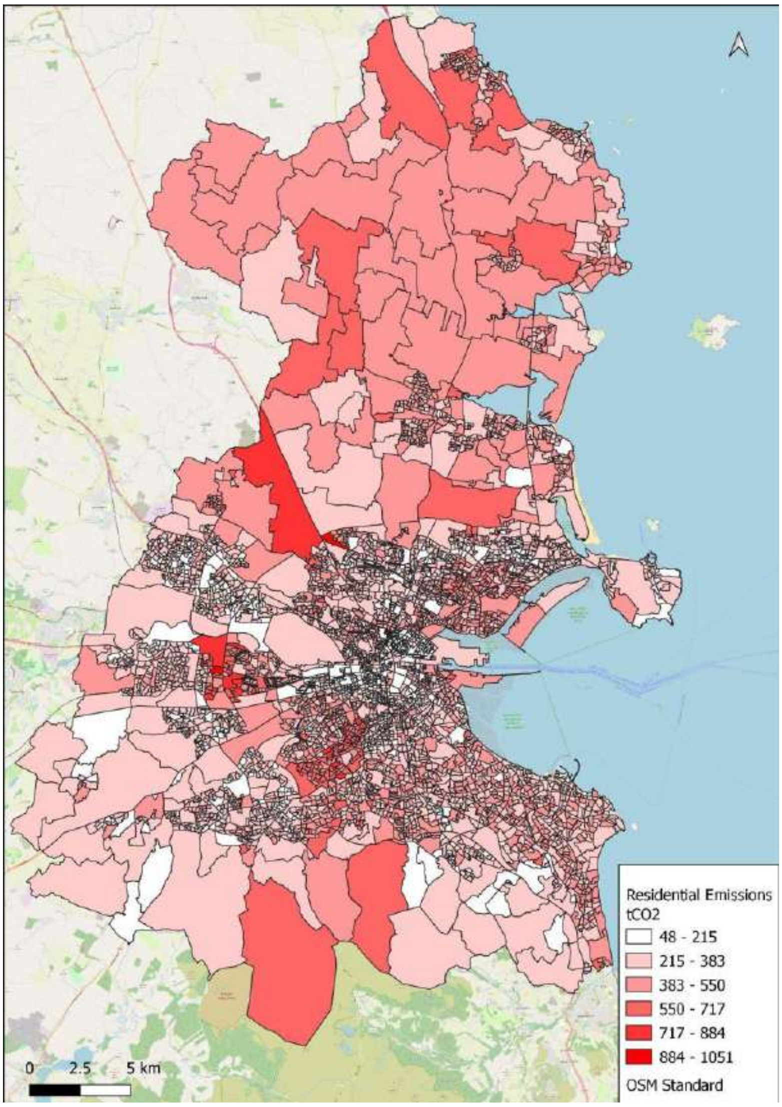

Figure 27: Emissions from the Residential Sector

Non-Domestic Buildings

The non-domestic sector includes commercial, public and industrial buildings. The main data source for the non-domestic sector is a detailed list of all rateable commercial buildings which was provided by the Valuation Office. This data includes a list of all the commercial properties, their location and respective floor areas in the Dublin Region. These properties were also broken down into different categories and types of use. The map on the next page shows the number of non-domestic properties in the Dublin Region and the chart underneath it shows the proportion of non-domestic properties by building category.

This data was used to link all the different non-domestic buildings and to generate the energy demand and emissions from the sector. The detailed findings for each sector are presented in the next sections.

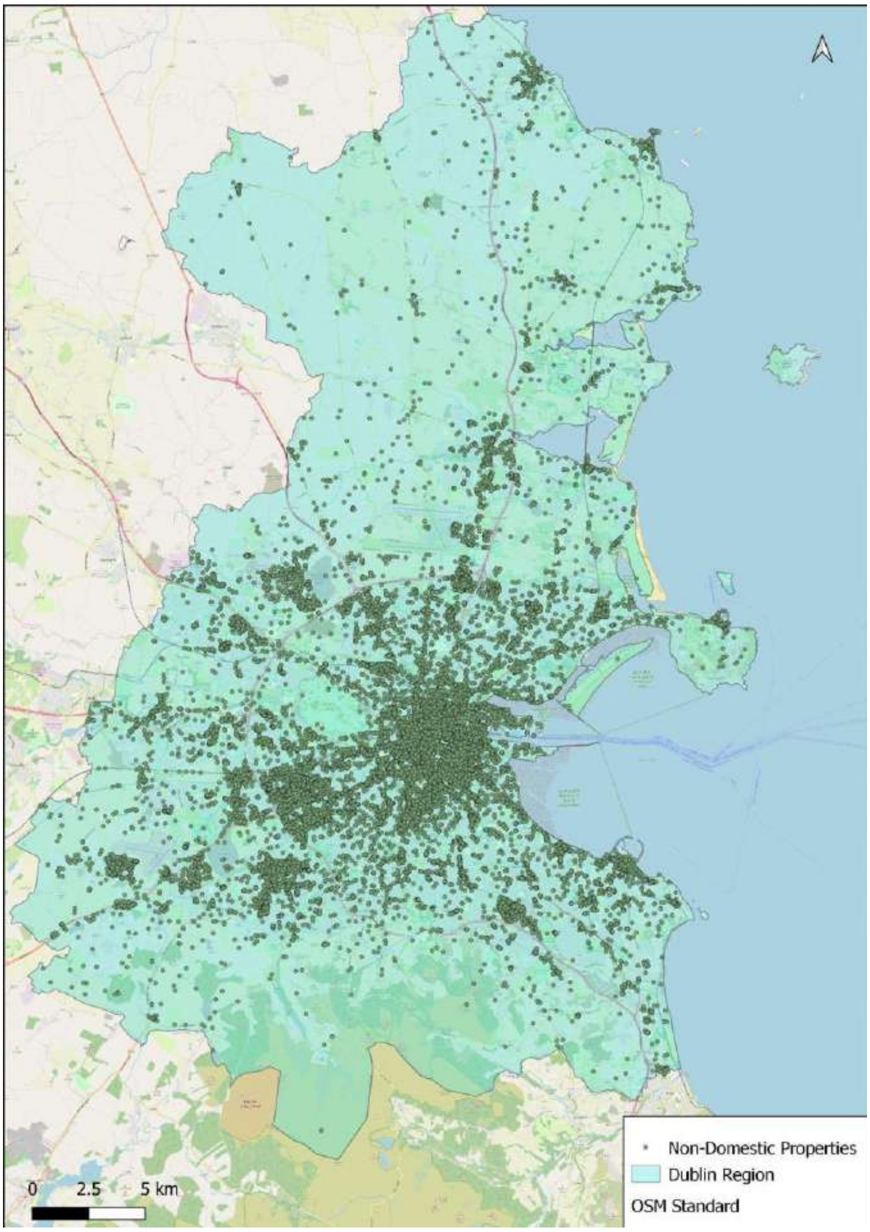

Figure 28: Non-Domestic Properties in Dublin

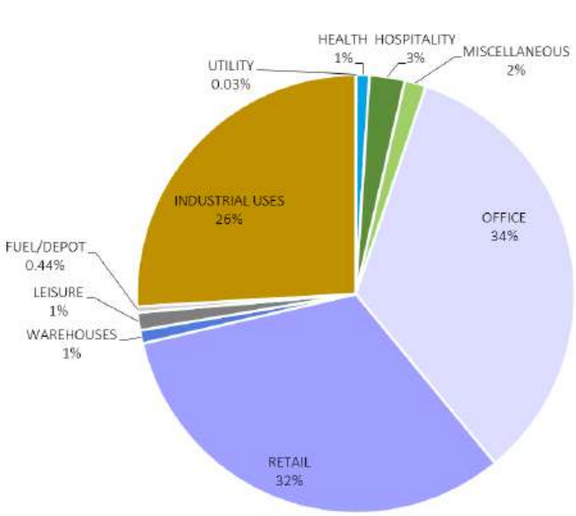

Figure 29: Non-Domestic Properties by Category

Public Sector

The total metered energy demand for the public sector in Dublin in 2018 was 1.23 TWh, of which 45% (559 GWh) came from electricity and 55% (676 GWh) from gas consumption.

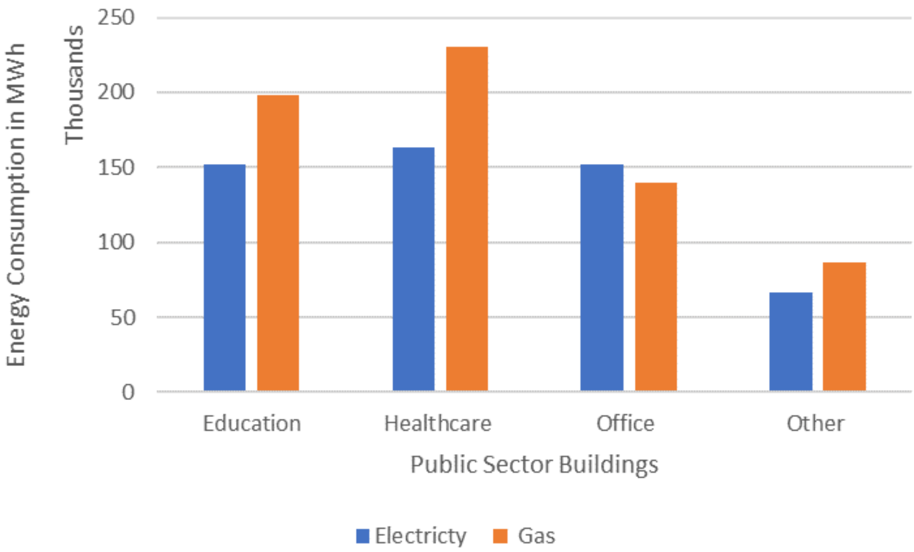

Figure 30: Public Buildings' Gas and Electricity Energy Demand

This resulted in a total of 303,276 tCO_2 of emissions emitted by public buildings in Dublin. Within this, healthcare buildings emitted the most CO_2 (100,081 tCO_2), followed by education buildings (90,982 tCO_2), offices (72,786 tCO_2) and other buildings (which include buildings such as post offices, public theatres and national galleries, etc.) at 39,425 tCO_2.

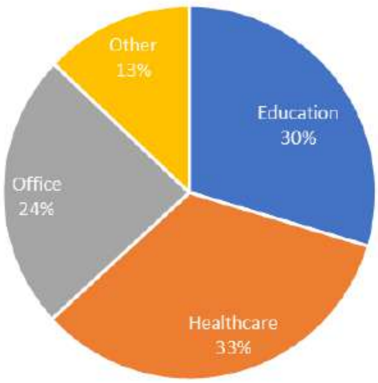

Figure 31: Public Buildings' Emissions Breakdown

Commercial

The chart on the next page shows the share of energy demand for electricity and fossil fuels for each of the commercial categories identified. It can be seen that fossil fuels by far make up most of the energy consumption. The total energy demand for this sector was 4,114.88 GWh, 1349.26 GWh of which was from electricity and 2765.62 GWh from gas consumption. Of all the commercial categories, the health sector had the highest reliance on fossil fuels (82% of the energy demand came from fossil fuels and 18% from electricity), whereas retail properties are heavily reliant on electricity (69% of the energy demand was met by electricity and 31% from fossil fuels).

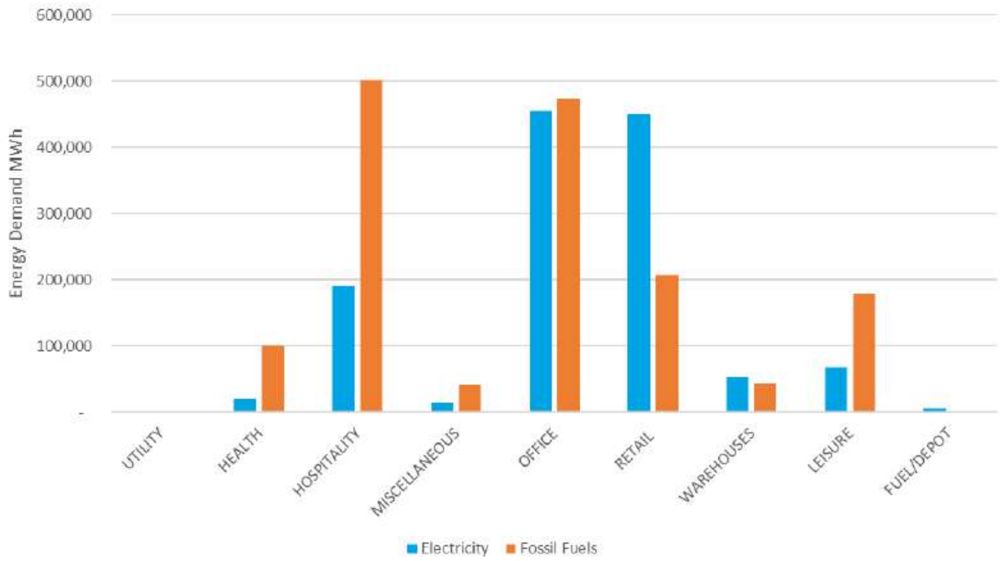

Figure 32: Energy Demand for Each Commercial Category

These commercial categories were then further broken down into building uses (as can be seen in the figure below). Commercial buildings and services resulted in a total of 1,016 ktCO_2 of emissions emitted. Within this, storage facilities (which include warehouse and bulk stores from the retail, office and leisure categories) and general offices each make up 26% of total emissions in the commercial sector.

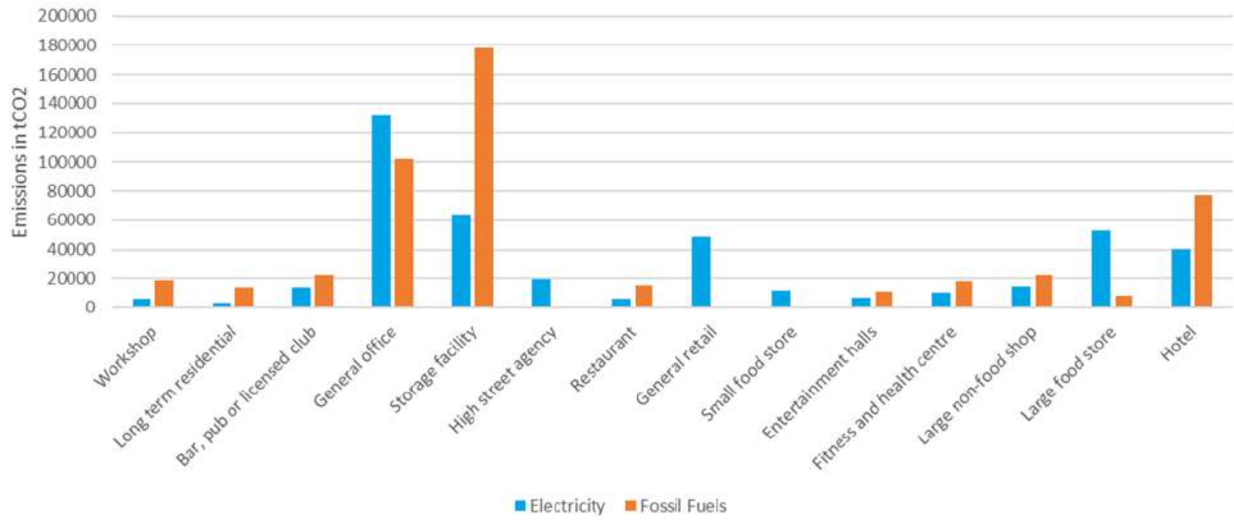

Figure 33: Commercial Use Emissions split into Electricity and Fossil Fuel Use

Industrial

The total energy demand for the industrial sites as reported to the EPA in 2018 was 4.36 TWh, of which 23% of energy demand was met by electricity and 77% by gas consumption. This resulted in a total of 1,248 ktCO_2 of emissions emitted. The figure on the next page shows the emissions from industrial businesses broken down into electricity and fossil fuels. It can be seen that this industry relies heavily on fossil fuels, as they make up most of the emissions.

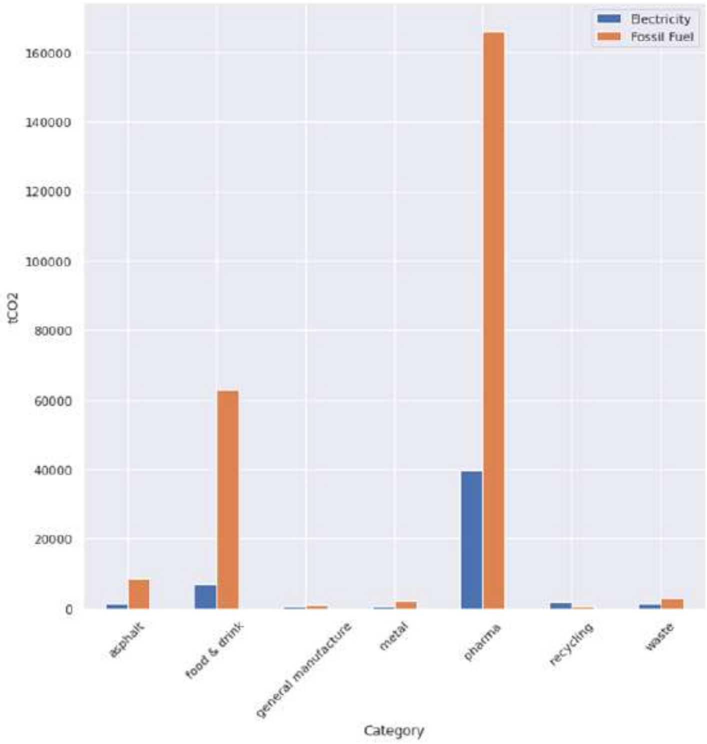

Figure 34: Industrial Emissions

The remaining energy demand (i.e. the industrial sites not accounted for by the AER) for this sector in 2018 was 0.72 TWh, of which 0.30 TWh from electricity and 0.42 TWh from gas consumption. This resulted in a total of 180,193 tCO2 of emissions emitted.

Total Non-Domestic Energy Use and Emissions

The total energy demand from non-domestic buildings is 6,300 GWh for commercial buildings and services (65%), the public sector (20%) and industrial uses (15%) (this does not account for ETS emissions). The figure on the next page shows the total energy demand in each small area. It can be noted that highest emissions pertain to areas within the region that have a high number of commercial properties and energy intensive businesses.

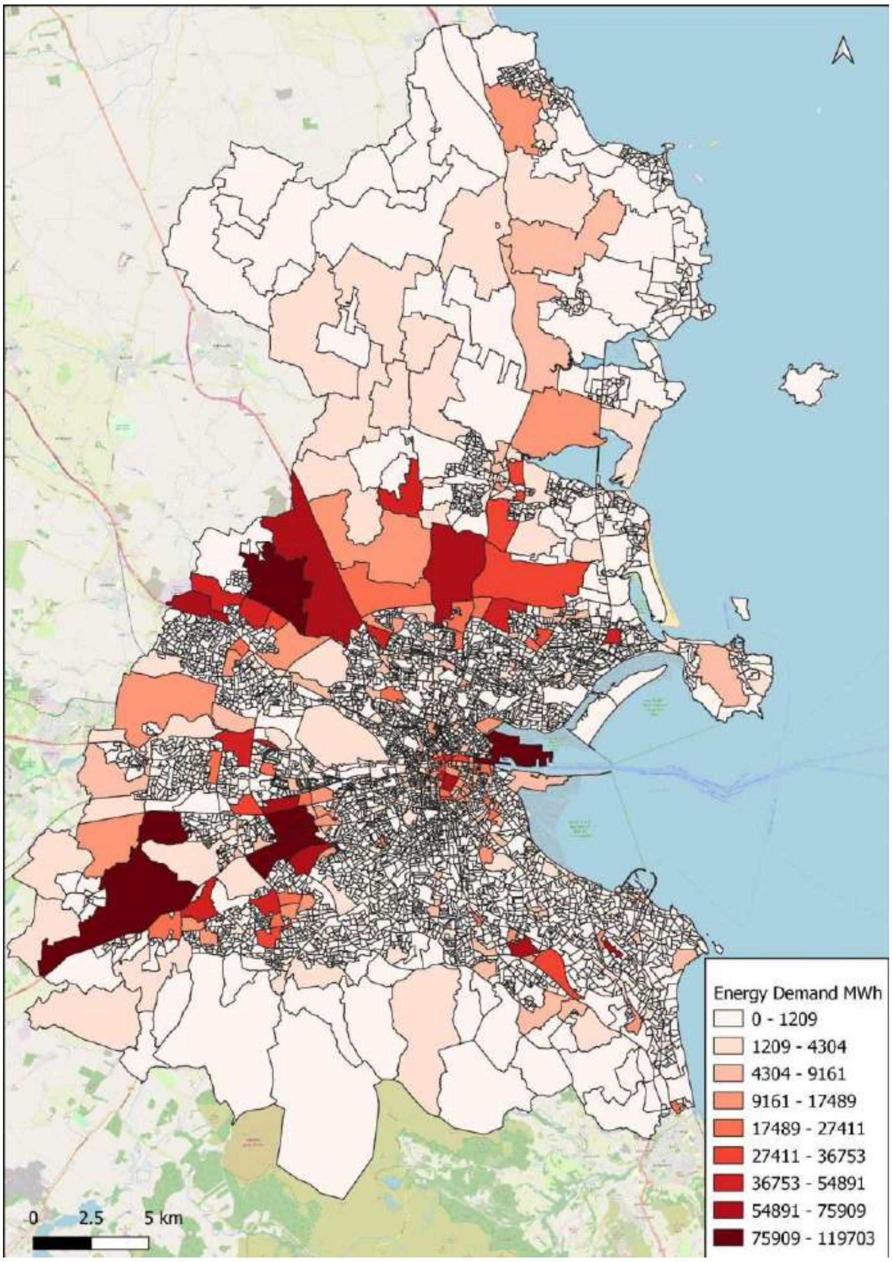

Figure 35: Commercial Energy Demand

Total emissions for the non-residential sector make up 1,589ktCO_2, of which 55% are emissions from fossil fuels and the remainder (45%) from electricity.

Total Energy Demand and Emissions from the Building Sector

Total energy demand from buildings and services accounted for 58% of total energy consumption in the Dublin Region (16,706 MWh)[51], 31% of the demand was met by electricity and the remaining 69% by fossil fuels (predominantly natural gas). The small area emissions from buildings can be found in Figure 36. Buildings and services accounted for 3,347.6 ktCO_2 (approximately 56% of total emissions); this might be attributed to the high building density in the region and Dublin's ageing housing stock with 78% of the stock in Dublin having been built prior to the year 2000, which is higher than the national average.

[51] This does not include data centres

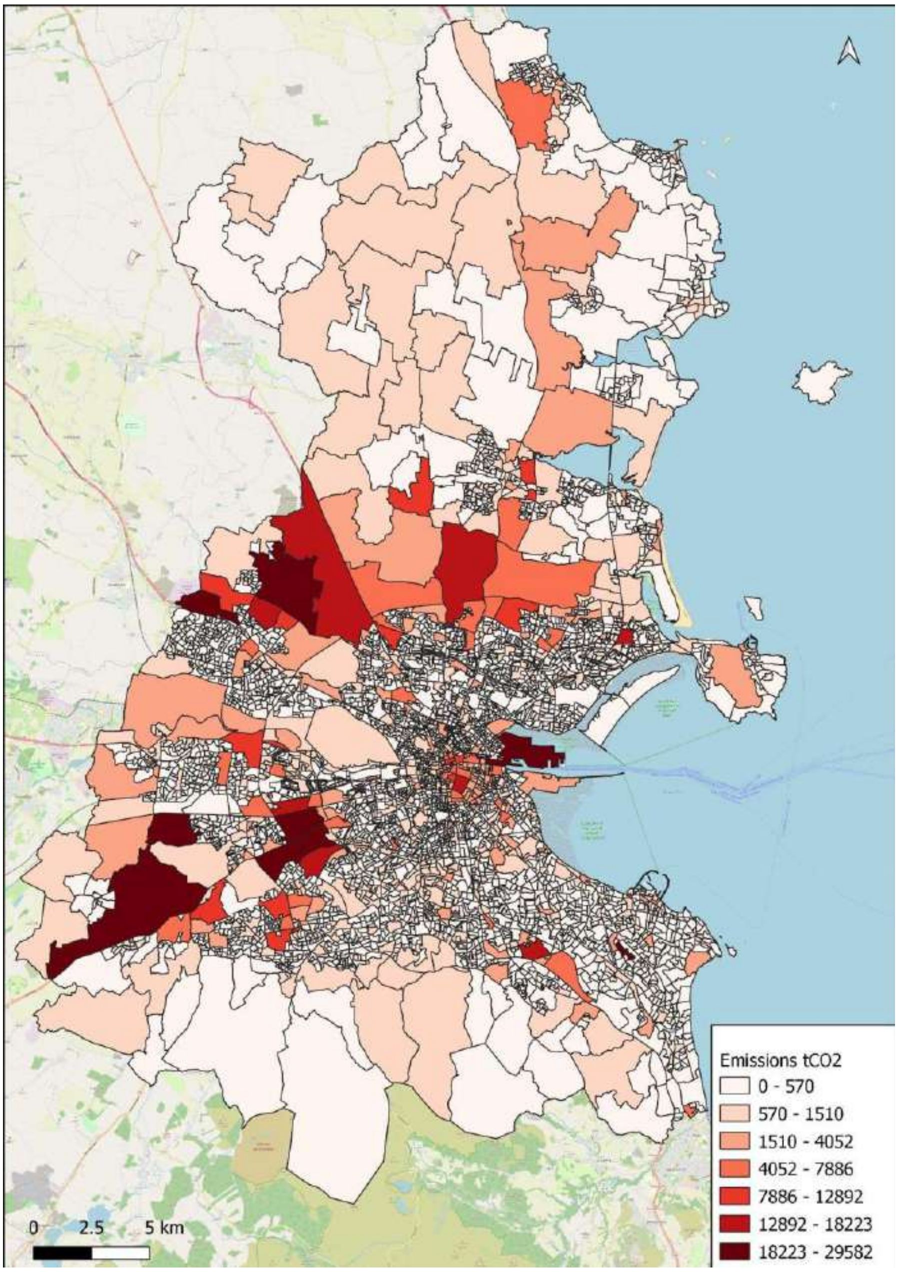

Figure 36: Building Emissions by Small Area

Building Energy Efficiency Upgrades

To meet 2030 and 2050 decarbonisation targets, the building stock will need to be highly energy efficient. This would mean that all new buildings are built to nearly zero-energy building (nZEB) standard (this is discussed in greater detail in the section - **New Buildings and Future Energy Demands**) and that the majority of existing buildings undergo energy efficiency upgrades or retrofits. Ireland's Long Term Renovation Strategy[52] suggests that by 2050, it is expected that more than 1.5 million buildings in Ireland will need to be retrofitted.

Ireland's Climate Action Plan, which sets out a roadmap to 2030 in line with the 2050 decarbonisation target, includes a number of actions for energy upgrades to 2030, some of which are listed below:

Residential Sector – Retrofitting 500,000 homes to a B2 BER or cost optimal equivalent or carbon equivalent

[52] https://www.gov.ie/en/publication/a4d69-long-term-renovation-strategy/

- Local Authorities upgrading their housing stock under Phase 2 of the social housing retrofit programme to bring dwellings to a BER level of B2 or cost optimal equivalent
- Installing 400,000 heat pumps in existing buildings

Commercial Sector – At least one third of total commercial properties to be upgraded to a B NDBER

- Public buildings need to meet a reduction of 50% in emissions

Details on existing building renovation regulations can be found in **Appendix B - Building Sector Methodology.**

Barriers to Energy Efficiency Upgrades

Barriers to building retrofits can be attributed to a number of different issues, most of these barriers are common to both residential and non-residential buildings. From Codema's Zero Together Survey,[53] which ran during September and October in 2021, participants who responded to the survey highlighted barriers such as cost, poor infrastructure and lack of information and awareness as barriers to those living in Dublin to take direct action. The Long Term Renovation Strategy also highlights that the key barriers around retrofits can be described as:

- Accessibility – making it possible and easy for decision makers to retrofit their buildings
- Affordability – retrofit costs can be quite expensive especially to meet specific building regulation standards
- Appetite – there is a need to make businesses and homeowners aware of the benefits of energy efficiency upgrades

Cost

One of the key constraints to retrofits is cost. The deprivation map shown on the next page shows the measure of deprivation for small areas[54] in the Dublin Region, with areas of high affluence shown as green and least affluent areas in red[55] (an energy poverty map, mapping residential dwellings that have a D1 BER or worse, a high unemployment rate and low deprivation index, can be found in **Appendix F Socio-Economic Impacts**). The deprivation index helps policy makers and researchers to identify disadvantaged areas and has demonstrated strong correlations with a range of health and social outcome measures across many countries.

[53] http://www.codema.ie/media/news/survey-national-government-most-responsible-for-tackling-dublins-fossil-fue/

[54] A 'Small Area' is the smallest geographical breakdown used in Ireland for statistical purposes. Each small area includes between 80-120 buildings.

[55] Deprivation Index > 30 - Extremely Affluent, 20 to 30 - Very Affluent, 10 to 20 - Affluent, 0 to 10 - Marginally Above Average, -10 to 0 - Marginally Below Average, -20 to -10 Disadvantaged, -30 to -20 - Very Disadvantaged , < -30 Extremely Disadvantaged

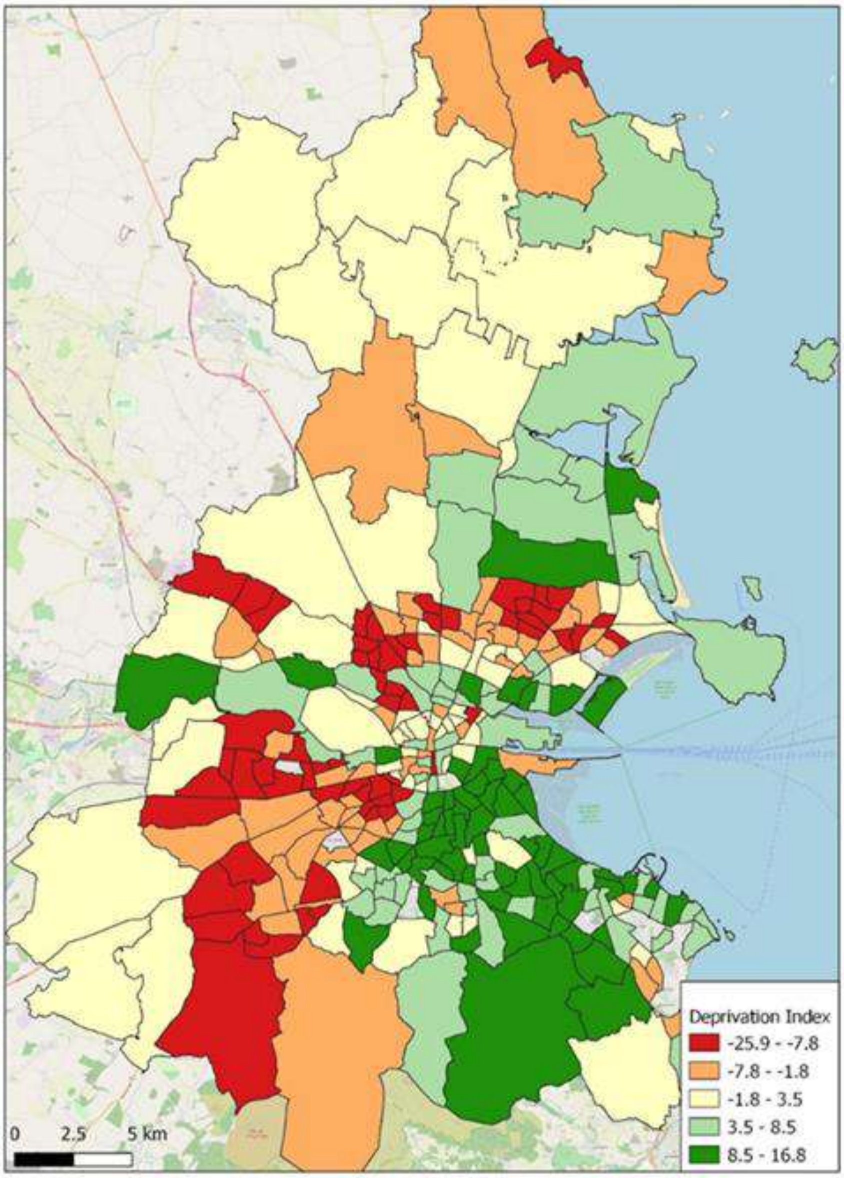

Figure 37: Deprivation Index Map for the Dublin Region. Source: CSO 2016 Deprivation Index

Considering that the average BER in Dublin for residential dwellings is a D2 and that the commercial sector is also an ageing and inefficient stock, the cost to retrofit these buildings will be quite high. This is even more so when specific heating technologies (such as heat pumps) would require a sufficiently energy efficient building to be installed and perform efficiently.

<u>Consumer Behaviour and Consumption Practices</u>

Although progress has been made in accelerating energy renovation in Ireland, it is widely accepted that there is a large gap between the actual and required level of investment. Cost and long payback periods for retrofits also make it difficult for customer buy-in. This can be further exacerbated by consumer behaviour and consumption practices. In general, higher rated dwellings (both new and buildings that have been retrofitted to high BER standard) tend to use more energy than predicted, as occupants become used to the higher comfort levels, while poorly rated dwellings tend to use less energy than predicted by choosing to leave zones of their home unheated.

Analysis of the rebound effect in residential dwellings, Aydin et al[56] compared theoretical consumption (based on that expected from the Energy Performance Certificate/Building Energy Rating) to actual consumption (based on metered gas consumption) for 710,000 buildings in the Netherlands. It was found that as energy efficiency gains change, the perceived cost of energy services generates shifts in consumption patterns in what is referred to as the Rebound Effect. In simple terms, the Rebound Effect is the percentage of the theoretical savings that are not realised in reality. The results of this study show a rebound effect of 26.7 % among homeowners, and 41.3 % among tenants. For this energy masterplan, an average of these figures has been applied to the calculated energy savings to provide a more realistic estimate of post retrofit demand.

Home and Business Tenure

Home and business tenure is an important consideration for building energy upgrades. People living or have a business in rented accommodations are less likely to take on any upgrades to their property, whereas owner occupied buildings are more likely to be retrofitted as the owner occupier will be seeing upgrade benefits in the reduction of consumed energy costs. This often means that for rented accommodation and business properties, building owners would have very little incentive to invest in costly measures to improve energy efficiency as they do not directly benefit from them. Introducing minimum energy performance standards for rented buildings might be a way to increase the rate of retrofits in these buildings.

This map of Housing Percentage Ownership was created using the open-access Small-Area Population Statistics (SAPS) 2016 data provided by the CSO. Ownership was calculated by dividing the total number of dwellings owned with a mortgage (T6_3_OMLH":"Owned with mortgage or loan"), together with the dwellings owned outright (T6_3_OOH":"Owned Outright") by the total number of dwellings ("T6_3_TH":"Total"). The colour ramp represents percentage ownership of the housing stock where red and green indicate a higher and lower ownership, respectively.

[56] Aydin, E., Brounen, D. and Kok, N., 2013. *The Rebound Effect in Residential Heating*. https://www.tilburguniversity.edu/sites/tiu/files/download/The%20Rebound%20Effect_EA300813.pdf

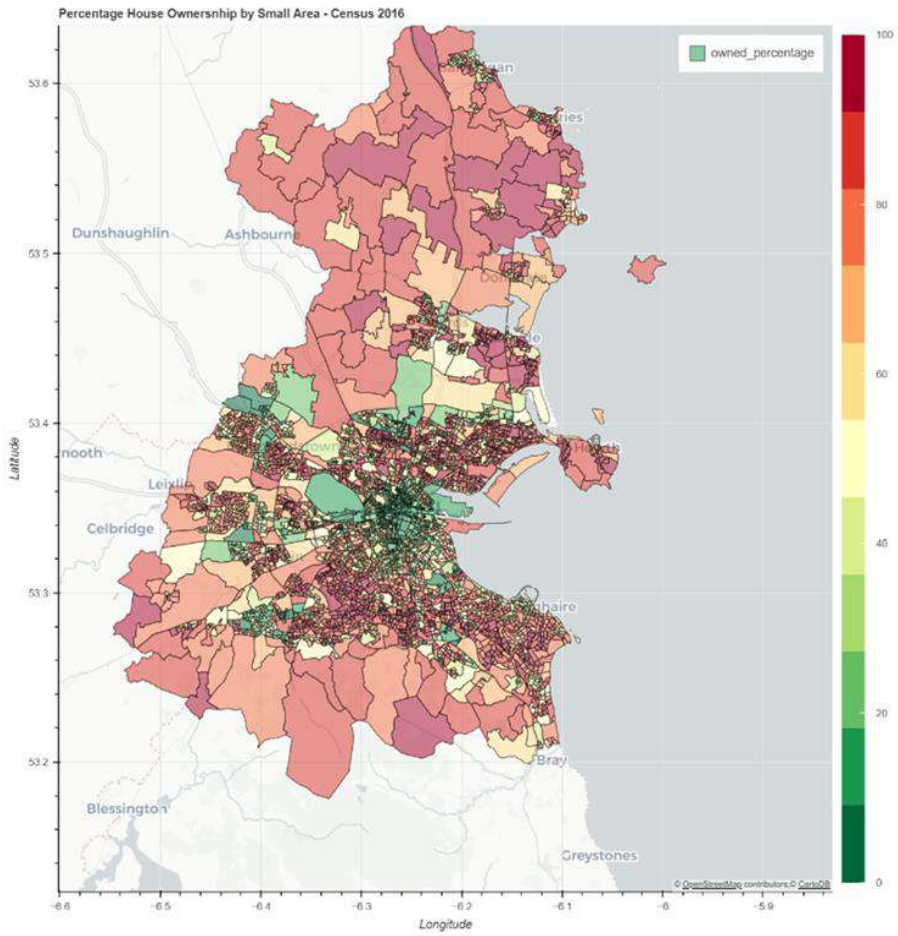

Figure 38: Home Ownership Percentages in Dublin by Small Area[57]. Source: Census 2016

The figure above shows the home ownership percentages in the Dublin Region. The lowest home ownership can be found in the inner city area and these areas overlap with areas that have a high number of apartments. For example, 52% of all residential buildings in Dublin 1, 2, 7 and 8 are apartments; these same areas also have poor BERs, with 68% of the residential stock with a D1 BER or worse. Therefore, these buildings (inner city apartments) will be some of the hardest to retrofit.

Technological Constraints

One of the main constraints to the adoption of individual building-level heat pumps is the requirement to have a sufficiently energy efficient building that allows the heat pump to supply adequate heat (enough to keep the building at a comfortable temperature) without detrimental effects to the HP's efficiency.

[57] https://codema-dev.github.io/map/housing-ownership/

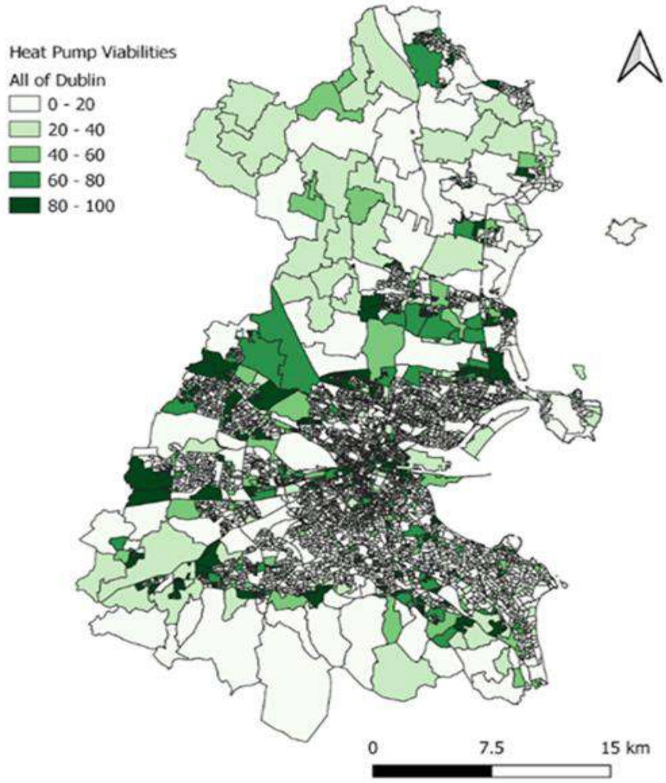

Figure 39: Current Heat Pump Viability in Dublin

The metric used to assess a building's suitability for heat pumps is known as the Heat Loss Index (HLI). In order for a residential dwelling to be deemed suitable it requires a HLI of 2 W/K.m^2 floor area or less[58]. The HLI can be defined as the total heat loss (fabric and ventilation losses). Where the HLI is between 2 and 2.3 W/K m^2, in some cases it may not be feasible to upgrade the home further, however a HLI of 2.3 can be accepted once the following criteria[59] are satisfied:

- Maximum exposed wall U-value 0.37 W/m^{2}K
- Maximum roof U-value 0.16 W/m^{2}K or 0.25 W/m2K where not accessible (e.g. flat roof or rafters)
- Maximum Window U value 2.8 W/m^{2}K* (and double glazed)
- Maximum Adjusted Infiltration Rate of 0.5 ac/h

The map of heat pump viability (shown on previous page) was created using Codema's synthetic building stock, it maps out the HLI indicators that are less than 2, to create a map of heat pump viability in each small area.

Heat pumps for the building sector are discussed in further detail in **Appendix C - Heat Sector Methodology.**

<u>Protected Structures</u>

Heritage buildings are protected under the National Monuments Acts[60]; protected structures and proposed protected structures are exempt from the requirements to have a BER.

[58] https://www.seai.ie/publications/Technical_Advisor_Role.pdf
[59] https://www.seai.ie/publications/Technical_Advisor_Role.pdf
[60] https://www.irishstatutebook.ie/eli/2004/act/22/enacted/en/print

'A protected structure is a structure that a planning authority considers to be of special interest from an architectural, historical, archaeological, artistic, cultural, scientific, social or technical point of view. '[61]

Owners of protected structures are legally obliged to prevent it from becoming endangered. Planning permission is needed to carry out work on a protected structure that could materially affect its character. This means that many types of work, which in another building would be considered exempted development, may not be exempted where the building is a protected structure. Depending on the nature of the structure and the features of interest, even work such as painting the interior or replacing windows could affect its character and require planning permission.

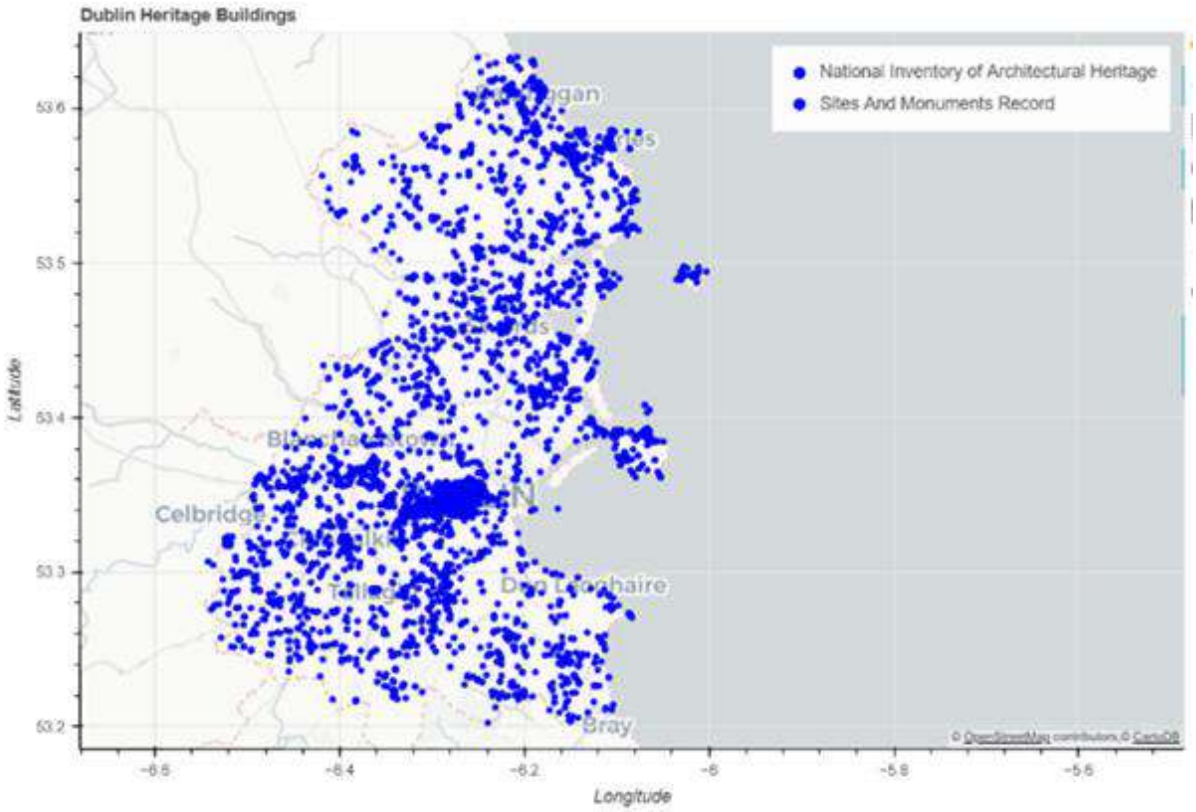

Figure 40: Dublin Heritage Buildings[62]

The map above shows all the heritage buildings that can be found in Dublin. The map was created using data from the National Inventory of Architectural Heritage and Sites and Monuments Record. In the Dublin Region, a total of 420 heritage buildings were identified; for the purpose of this project these buildings were not considered suitable for energy efficiency upgrade works.

Building Renovation Passports

To meet the scale of deep retrofit needed for the building sector, a big increase in energy efficiency measures is needed. Overcoming the current shortfall in action and investment requires addressing key barriers, including low levels of awareness among homeowners and occupiers and a lack of information about appropriate retrofit measures and the financial options available to pay for them. Building Renovation Passports (BRPs) can help meet this challenge; BRPs typically are masterplans for retrofit and include a record of works and a long-term renovation roadmap that identifies future retrofits and installations to decarbonise the property, along with links to contractors, other service providers and finance options.

BRPs can be employed to ensure a holistic and technically sound approach to planning and implementing renovation works. They are also key to prevent 'lock-ins' and can facilitate a step-by-step approach to deep retrofits. The BRPs can

[61] https://www.sdcc.ie/en/services/planning/heritage-and-conservation/protected-structures/
[62] https://codema-dev.github.io/map/hertitage-site-map/

be especially useful to help tackle consumer decision-making barriers by providing the information and guidance to enable property owners to improve their properties and reduce emissions. BRPs are being considered as a key solution in the EU, these voluntary passports have also been cited in the 2018 Energy Performance Building Directive (EPBD)[63], to avoid retrofit lock-ins and encourage phased quality deep retrofit. One of the aims of the amended EPBD is to improve energy advice services across the EU. Existing BRPs have proven[64] that they can be an effective way of providing renovation advice, whilst also taking into account the long-term vision for the building stock.

New Buildings and Future Business-As-Usual Energy Demands

Increases in the building sector energy demand to 2030 can be attributed to a number of variables. The main impact on future predicted energy demand can be linked to population growth, which is coupled with an increase in both residential and non-residential buildings, which is driven by planning developments. The Economic and Social Research Institute (ESRI) has published population projections and annual average population growth rates for Ireland, this is further broken down by region (table 65 found in **Common Assumptions** Section). For Dublin it has been estimated that the population from 2016 to 2040 would increase by 0.9% annually.

The National Planning Framework[65] (NPF) for Ireland is projecting a need for 550,000 more homes by 2040. Within this, a quarter of these homes (137,500) are planned for Dublin. The NPF has also identified that over recent years there has been an '*ongoing shift in population and jobs towards the east counties'*.

It should be noted that even though the number of buildings (both residential and non-residential) are set to increase, building regulations, particularly for new builds, have been setting out strict guidance on energy performance in buildings.

All new buildings are to be built to nearly zero-energy building (nZEB) standard, which is defined as a building that has a very high energy performance, as determined in accordance with Annex I of the Energy Performance in Buildings Directive, i.e. the Dwelling Energy Assessment Procedure (DEAP) and Non-domestic Energy Assessment Procedure (NEAP). The nearly-zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby.

Details on new building regulations can be found in **Appendix B - Building Sector Methodology.**

Business-As-Usual Energy Demands

In order to project future demands, Codema engaged with EirGrid's Energy Modelling team. Making use of EirGrid's support and report 'All Island Generation Capacity Statement 2019 -2028'[66], the growth factors used in this analysis were developed using forecasted economic growth from the ESRI in conjunction with historical demand data. The demand forecasts also had to account for increases in both the housing stock and commercial properties in future years, whilst also considering the negating effects of increased energy efficiency in buildings.

Conveniently, these demand estimates were provided by EirGrid under three key headings of residential, commercial and data centres, each of which had their own respective growth factors. Interestingly, the energy demand for 2021

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[63] Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency

[64] European Commission, Directorate-General for Energy, Zuhaib, S., Volt, J., Fabbri, M., Technical study on the possible introduction of optional building renovation passports : final report, Wouters, P.(editor), Publications Office, 2020, https://data.europa.eu/doi/10.2833/760324

[65] https://npf.ie/project-ireland-2040-national-planning-framework/

[66] https://www.eirgridgroup.com/site-files/library/EirGrid/EirGrid-Group-All-Island-Generation-Capacity-Statement-2019-2028.pdf

was set to decrease from 2020, due to the economic downturn from the COVID-19 pandemic. However, this is set to revert and continue in an upward trend from the year 2022.

These electricity growth factors were combined with projected heat demand growth factors developed by Codema. Heat demand projections accounted for residential and non-residential (commercial and industry) buildings and the increase in new buildings (both residential and non-residential). Future scenarios also accounted for increased energy efficiency in buildings with fabric upgrades and the rebound effect, and buildings with no fabric upgrades. For this BAU, it was assumed that fabric upgrades will be undertaken to bring buildings to threshold U-Values (these threshold U-Values are described in detail in the **Appendix B - Building Sector Methodology, Potential for Building Efficiency and Carbon Savings for the Dublin Region**), thus these projected figures might be slightly lower than future building demands.

Overall, for the building sector, Codema estimates that the business-as-usual energy demand is likely to increase by 5% by 2030 and a total increase of 14% by 2050 (from 2020 figures). The residential sector is set to increase by 11% over the 30 year period; this means that the future BAU residential energy demand in 2050 is estimated to be 11,529 GWh, whilst commercial buildings are set to increase by 21%, resulting in a future BAU demand of 6,152 GWh by 2050. Data centres and the increase in energy demand generated by these proposed developments will be discussed in further detail in **Appendix D – Electricity Sector Methodology.**

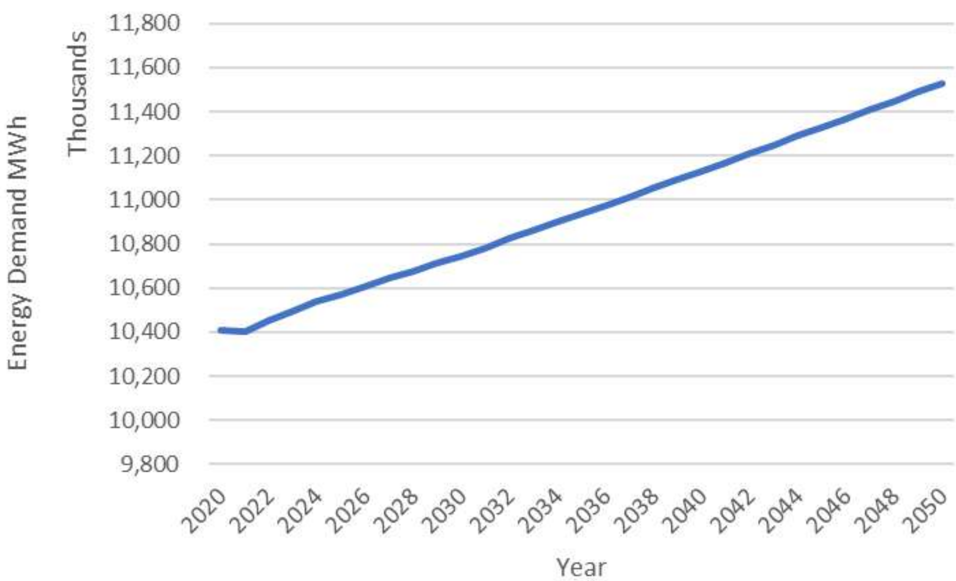


Figure 41: Dublin's Residential Energy Demand Forecast

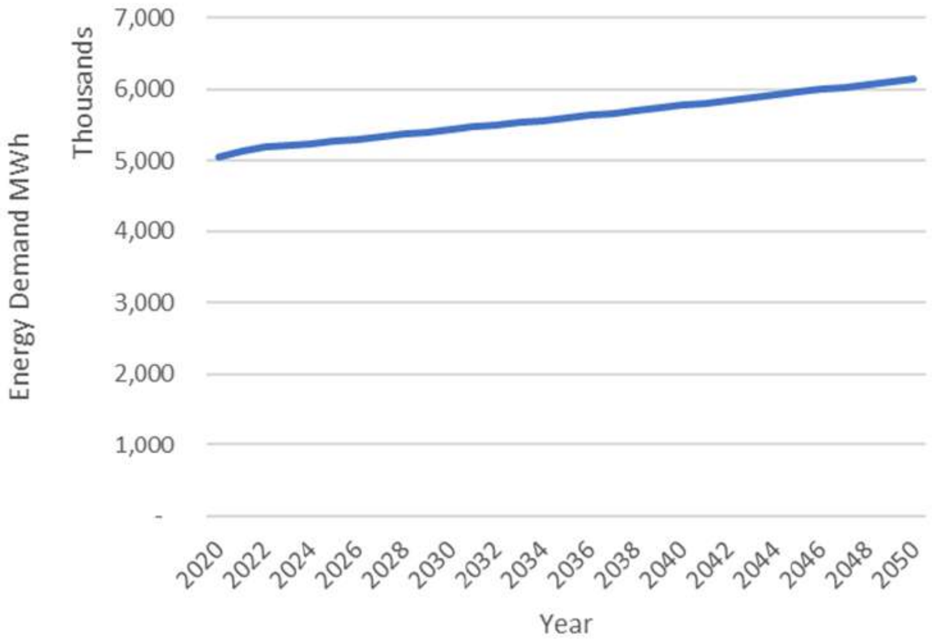


Figure 42: Dublin's Commercial Energy Demand Forecast

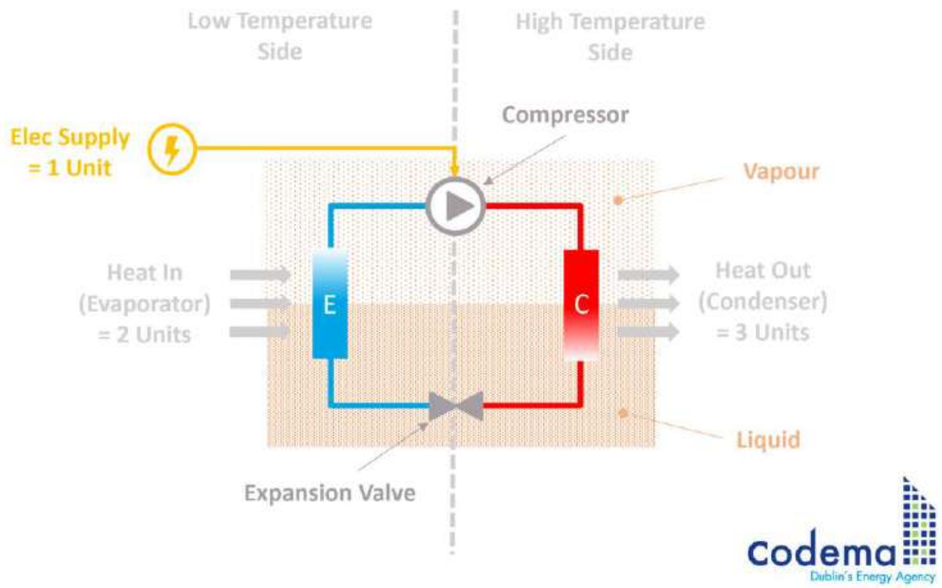
Heat

The heat analysis performed as part of the master plan study looked at two main low-carbon heating options, district heating and heat pumps. The adoption of biomethane[67] and limited quantities of green hydrogen (20% by volume which equates to 7% by energy content which can be accommodated within existing gas infrastructure) have been included in this analysis to produce future carbon emission factors for the gas grid. It should be noted that the use of these gases cannot deliver full decarbonisation of the entire heat sector (in the current quantities needed) and should be prioritised for high-exergy applications such as backup power generation or as a feedstock for specific industrial processes where needed rather than for low-exergy applications (space heating and hot water preparation).

Heat Pumps

This heat pump analysis focuses on electrical heat pumps. An electric heat pump is a device that can extract heat from a source at a lower temperature (air, water, waste heat) and increase its temperature to a usable level for injection into a building to provide space and hot water heating. This is made possible through the use of a refrigerant in a vapour-compression cycle. This operates in the same way a fridge does but rather than extracting heat from your fridge and rejecting it using the coil at the back of your fridge, an ASHP extracts heat from the external air and injects it into your home.

In this refrigeration cycle, heat is absorbed from a source by the evaporator causing the refrigerant to evaporate. This is then compressed by a compressor which raises the refrigerant temperature and then condenses in the condenser where it gives up its heat and converts back into a liquid. The figure below shows the elements for a heat pump with a coefficient of performance (efficiency) of three, i.e. three units of heat is produced for every unit of electricity consumed. This is representative of the annual average efficiency of a well performing air-source heat pump. Current average CoP for heat pumps in Ireland is approximately 2.8 but it is believed that a CoP of 3 or higher will become easily achievable as designers and installers increase their experience of optimising heat systems which use heat pumps.



This analysis focuses on air-source heat pumps (ASHP) and their performance when compared with district heating (DH). The reasons for considering ASHP rather than heat pumps that use surface water or ground source heat pumps are the availability of ground and surface water heat sources could not be accurately determined for every installation

[67] In line with the potential outlined by GNI discussed in Appendix C

whereas air is widely available across the entire county, ASHPs are currently the most commonly installed type of heat pump in Ireland. Air source heat pumps use ambient air as their heat source.

The efficiency of a heat pump varies depending on the difference in temperature between the source (the outdoor air) and the sink (the flow temperature in your radiators, hot water cylinder). The greater this difference the less efficient your heat pump will be. When buildings are less efficient they leak heat faster through poorly insulated fabric or poor air tightness. In order to be able to replace this heat at a fast enough rate you have two main options either increasing the size of the heat emitters (e.g. larger radiators or underfloor heating) or increasing the temperature. If the size of the emitters is kept the same then the flow temperature will need to be kept at a higher level to maintain the comfort in the building which leads to reduced efficiency but also in the case of heat pumps the need for larger heat pumps which are more expensive. For these reasons it is important to look at the heat loss of a building when considering its suitability for heat pumps. This is discussed in greater detail in Appendix B and C where heat pump viability maps for Dublin have been produced.

District Heating

A district heating scheme consists of an insulated pipe network, which allows heat generated from a single or several larger centralised source(s) (energy centres) to be delivered to multiple buildings to provide space heating and hot water.

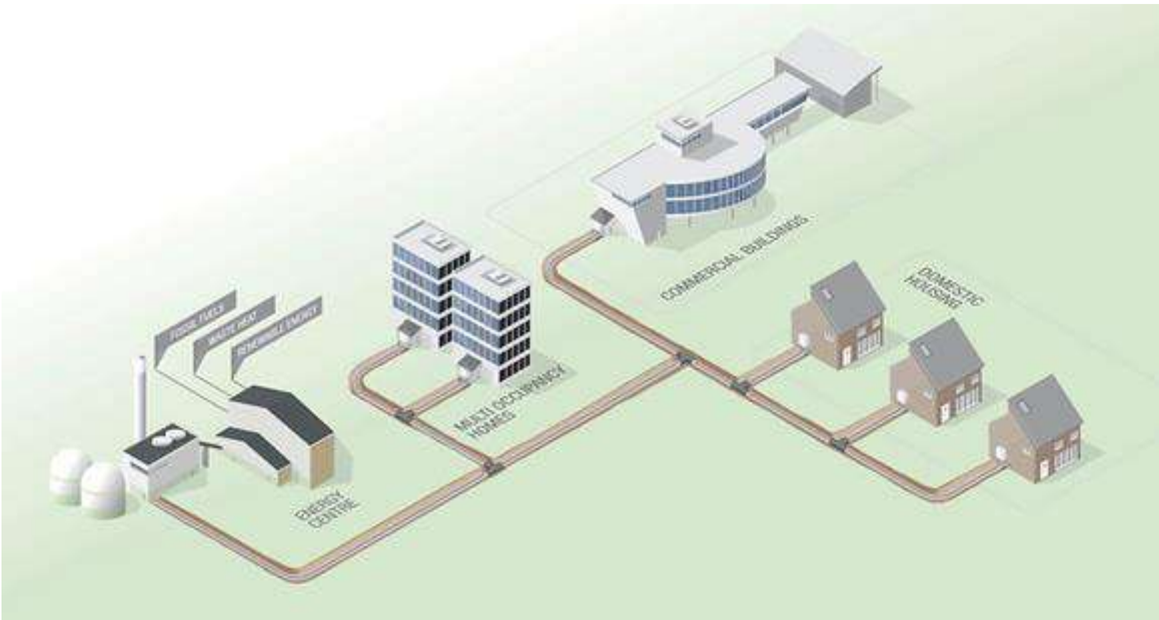


Figure 43: Indicative Diagram of District Heating System (Source: REHAU)

DH networks benefit from economies of scale, the reduced coincidence of heat demand between different customers leading to lower capacity requirements (when compared with multiple building level units), increased efficiency of larger heat generation units and the reduction in maintenance costs of having a centralised plant. These benefits **allow heat to be generated more efficiently and at a lower cost**. Having fewer, larger heat generation units when compared with having an individual, building-level heating plant also allows for easier decarbonisation of heat in the long term, as it requires less individual heating units to be replaced when adopting newer technologies. These large-scale heating systems can also dramatically reduce the carbon emissions associated with heating **without the need for significant retrofitting of buildings**.

District heating is technology agnostic and has the inherent flexibility to **utilise multiple, diverse, locally available, renewable and low-carbon heat sources**. This means customers are not dependent upon a single source of supply. This can help guarantee reliability, continuity of service and can introduce an element of competition into the supply chain, where desired. District heating can also allow waste heat (e.g. from electricity generation, industrial processes, etc.)

which is often lost, to be captured and used to supply heat to homes and businesses, reducing the need to consume further fuel and significantly reducing carbon emissions and the cost of heat.

Greater utilisation of green electricity can also be achieved through the development of DH networks. For example, heat pumps allow electricity to be converted into heat, which can be stored as thermal energy in the district heating network's pipes and thermal storage vessel, effectively acting as a large thermal battery. This is done at a fraction of the cost of other electrical storage methods and allows the electrical grid to be balanced during periods of low electrical demand (e.g. night time). This off-peak demand allows intermittent, renewable generation technologies such as wind turbines to run during these periods, where previously they could not, and thereby increase the green contribution to the local energy system. It is for these reasons that many of the most sustainable countries in the world have a large proportion of heat supplied by district heating systems. For example, DH plays a key role in the sustainability of cities like Copenhagen and Stockholm, where more than 98% and 80% of buildings are supplied by a DH network, respectively.

District heating is a low-carbon, low-cost method of supplying heat to a community, district or region and aligns with the energy and climate change ambitions to decarbonise heat in the region. DH has not been widely implemented in Ireland but there is now an increased focus on methods of decarbonising heat supply, as Ireland did not meet EU 2020 renewable energy targets in this area, and going forward, Ireland's 2030 targets will focus more on CO_2 emissions from the heat and transport energy sectors.

City-wide DH schemes are typically started and developed by establishing a number of smaller, stand-alone networks (or nodes), which are subsequently connected together into a larger scheme. This is particularly typical in publicly-led DH schemes in the UK, where the large capital expenditure required to implement a full city-wide scheme may not be easily accessed. Growing a large-scale DH system in this way allows the most financially attractive schemes to be established first, which then support the connection into adjoining areas that may be less financially attractive and ensures successful growth of the network.

Figure 44: Potential Benefits of District Heating (Source: Developing District Heating in North-West Europe: A Guide for Public Sector Organisations, Codema (2019))

Heat Sources for District Heating Networks

This section of the report outlines some of the heat source options available within the Dublin region to supply the areas feasible for district heating discussed in the Heating Pathway. This section gives a breakdown of the existing heat sources within the County.

Heat Source Summary

Heat sources that arise as a by-product of electricity generation, industrial activity, the natural environment or from existing infrastructure are low or zero-carbon and often go to waste. Codema estimates that almost 3,500 MW of heat from these sources (including both low-grade and high-grade heat) is currently being wasted in Dublin, equating to 24,244 GWh of wasted heat per annum. These sources could reduce the total fossil fuel bill for Dublin by €1.01 billion per year and reduce the region's exposure to price fluctuations and security of supply issues in the oil and gas markets. The flexibility offered by DH supply means it is possible to continually connect new secure local sources to the network. This also offers increased price stability and security for customers.

The use of existing local heat sources can provide many advantages to a DH network, such as:

- Increased security of supply
- Lower cost or free heat as it is already being lost to the environment – improving the economic case for the DH system
- Low or zero-carbon emissions as it is a by-product of a separate primary process – reducing emissions associated with heating
- Where heat pumps are being used, district heating networks can be used to balance the electricity grid and increase the proportion of renewable energy that can be utilised

The heat source map created by Codema assesses 18 different heat source types in the county and utilises data from approximately 70 different sources. The heat sources that were assessed are listed below with more details on what they are and how they were quantified given in the Heat Source Description and Heat Source Assessment Methodology sections in the appendices.

Commercial Sources:

- Flue gas heat recovery
- Industrial process heat recovery
- Commercial CHP excess heat
- Excess heat from existing biomass installations
- Commercial building cooling system waste heat (e.g. data centres, cold storage facilities)

Infrastructural Sources:

- Power plant waste heat (EfW and conventional power stations)
- Electrical transformer waste heat
- Landfill waste heat
- Landfill biogas
- WWTW waste heat
- WWTW biogas/sludge incineration
- Sewage pipe waste heat

Environmental Sources:

- Air-source heat pumps
- Surface water (rivers, lakes, canals)
- Seawater
- Ground source heat pumps (shallow)
- Deep geothermal
- Mine water

Heat Source Breakdown

The figure below provides a breakdown of the percentage available heat sources by their total estimated heat capacity in GW. For further details on how these were calculated and likely available temperatures from each source please consult **Appendix C - Heat Sector Methodology** of this document.

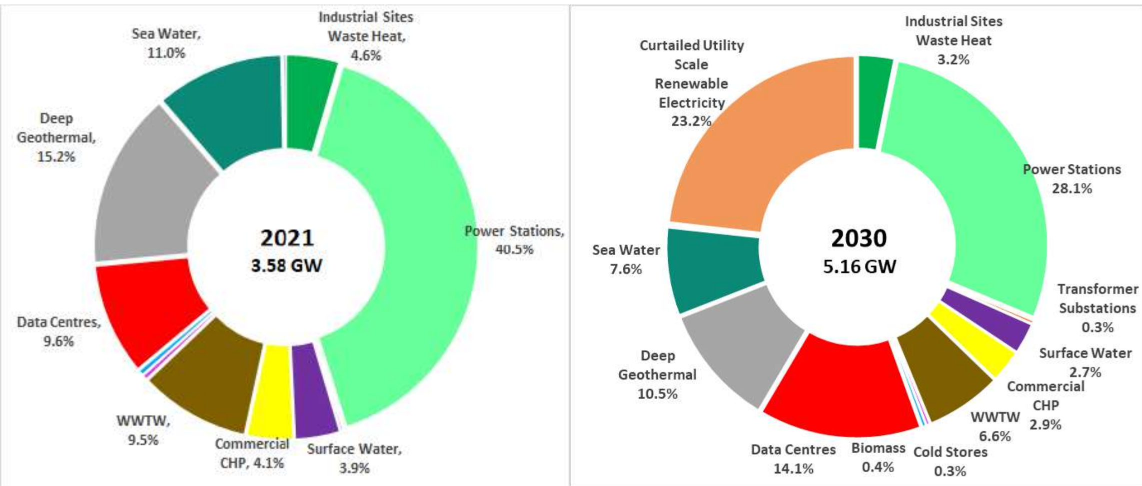


Figure 45: Heat Capacities of Potential Heat Sources in Dublin

It should also be noted that the capacity figure for the surface water heat loads shown in the figure above is a conservative one, as it is based on the Q95 flow (i.e. dry weather flow). This flow rate was chosen based on the assumption that the source waterways are fisheries and as such, have limits on the degree to which their original temperature can be altered without adverse impacts on the fishery. This also assumes a constant heat extraction rate. It may be possible to have variable extraction controlled by the source temperature to prevent excessive cooling of the source. Under these conditions, the mean flow could be used; this would increase the potential heat capacity from surface water by a factor of seven. If it was assumed that there is no impact on fisheries and therefore that the reduction in river temperature is only limited by technical constraints, then this capacity could increase by a factor of 12 compared to what is shown in the graph.

Deep geothermal heat sources were also considered within the County. The methodology for assessing the heat capacity of this resource was developed by Geological Survey Ireland (GSI) in conjunction with Codema, drawing on information from geothermal exploration studies carried out within the Dublin area. District heating networks are seen as key enabling infrastructure for the utilisation of low-enthalpy deep geothermal resources in Ireland.

In the future when large renewable electricity installations are likely to be prevalent in the region, there will also be an additional heat source in the form of curtailed electricity generation. Curtailed generation is electricity that is generated by renewable sources such as wind or solar but that cannot be used due to lack of demand or constraints on the electricity grid. This renewable electricity can be converted into heat via heat pumps or electric boilers to provide heating. In this respect, DH can also provide services to the grid in terms of frequency response and grid balancing. The utilisation of otherwise curtailed renewable electricity via DH also facilitates the use of cost-effective large-scale thermal energy storage which is a fraction of the cost of battery storage and benefits from a much longer lifespan. This source has been included in the 2030 heat source breakdown. It should be noted that the assumed curtailment in this assessment of 8.6% (based on the average three-year curtailment from 2018 to 2020 from EirGrid[68]) for 2030. If renewable generation outstrips demand in the way it should in the coming years, this potential curtailment figure is likely to increase (Codema conservatively estimate this at 18% for 2050 based on significant base load in Dublin and significant interconnection adoption), particularly if DH or other systems (batteries, etc.) providing grid balancing are not also developed.

It is also worth noting that the availability of commercial CHP waste heat is likely to increase due to developments in the regulating of data centres where it is expected that data centres will now use on-site generation more frequently

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68 http://www.eirgridgroup.com/site-files/library/EirGrid/Annual-Renewable-Constraint-and-Curtailment-Report-2020.pdf

to support the electrical grid in high demand periods. This has not currently been accurately reflected in the 2030 heat source breakdown as details around typical run hours of such installations is largely unknown and may differ from standard CHP operations, which look for a minimum of 3,000 hours per year to be cost effective. With growth in electrical demand (not related to data centres) also set to increase due to the electrification of heat and transport, distributed generation such as CHP engines may become more widely spread to reduce bottlenecks on the electricity grid (commonly referred to as non-wires alternatives or NWAs); this could further increase the the availability of CHP waste heat for utilisation in DH networks.

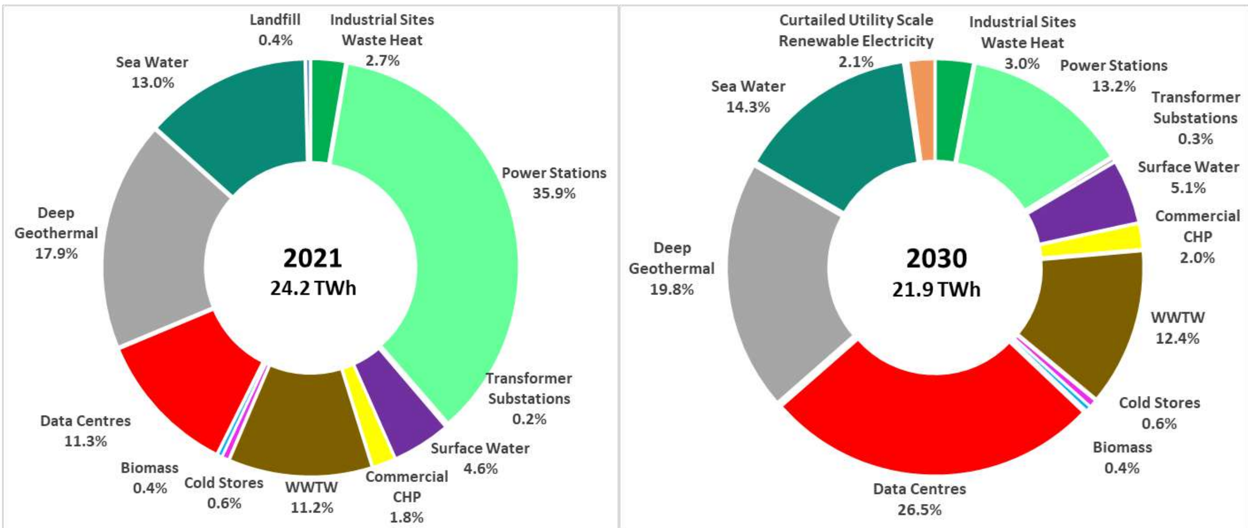

Figure 46: Breakdown of Estimated Total Heat Available for 2021 and 2030 in Terra-watt hours (TWh)

These sources have been broken down based on their average supply temperatures in the graphs below. This provides an indication of the quantity of higher temperature heat that could be utilised for direct use in DH networks (>60°C) without requiring heat pumps. The medium temperature sources which can supply heat between 20°C and 60°C would likely require a heat pump to bring them up to a usable temperature for typical DH networks but these could achieve very high COPs, likely to be above 3.5 and perhaps up to 12 (i.e. 12 units of heat for every 1 unit of electricity). The low temperature range (<20°C) would require heat pumps to raise their temperature to a usable level. Even when using the same sources as individual building heat pumps, these large-scale heat pumps generally provide better COP than the smaller alternatives. This is due to a number of reasons; these large-scale HPs are continually monitored to ensure their performance is optimised, they have continual maintenance to ensure efficient operations and the economies of scale allow for use of two-stage compression, which improves efficiency when using lower temperature sources.

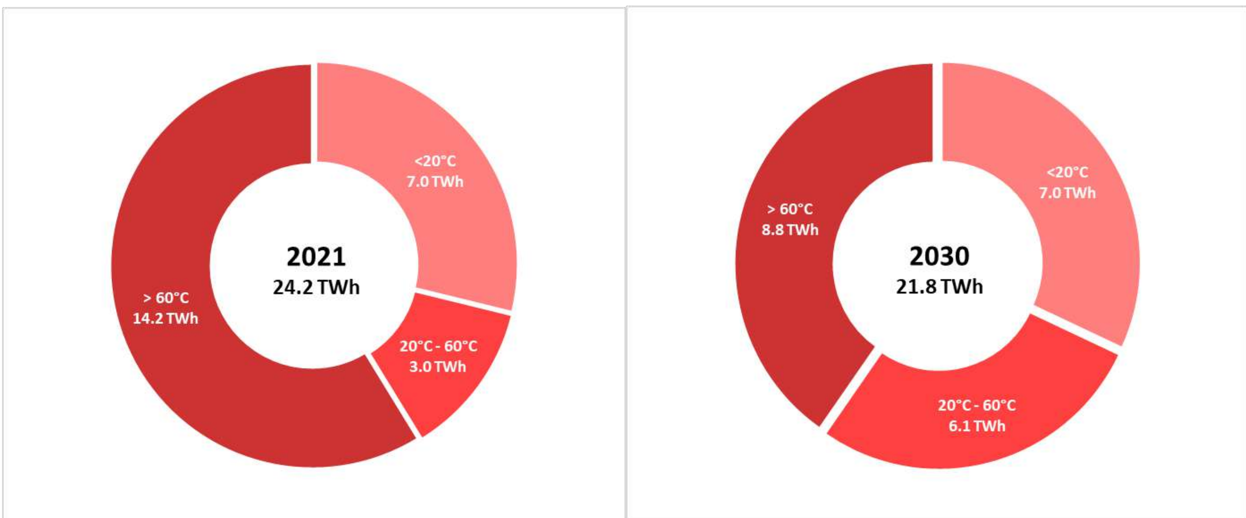

Figure 47: Breakdown by Temperature of Estimated Total Heat Available for 2021 and 2030 in Terra-watt hours (TWh)

The map below shows the location of the various heat sources identified in Dublin as part of this study. This map identifies 538 heat sources, which could supply existing or future district heating networks. It should be noted that this may not represent an exhaustive list of heat sources but is based on the best available information. Industrial and commercial heat sources in particular may be underrepresented in this analysis due to lack of data.

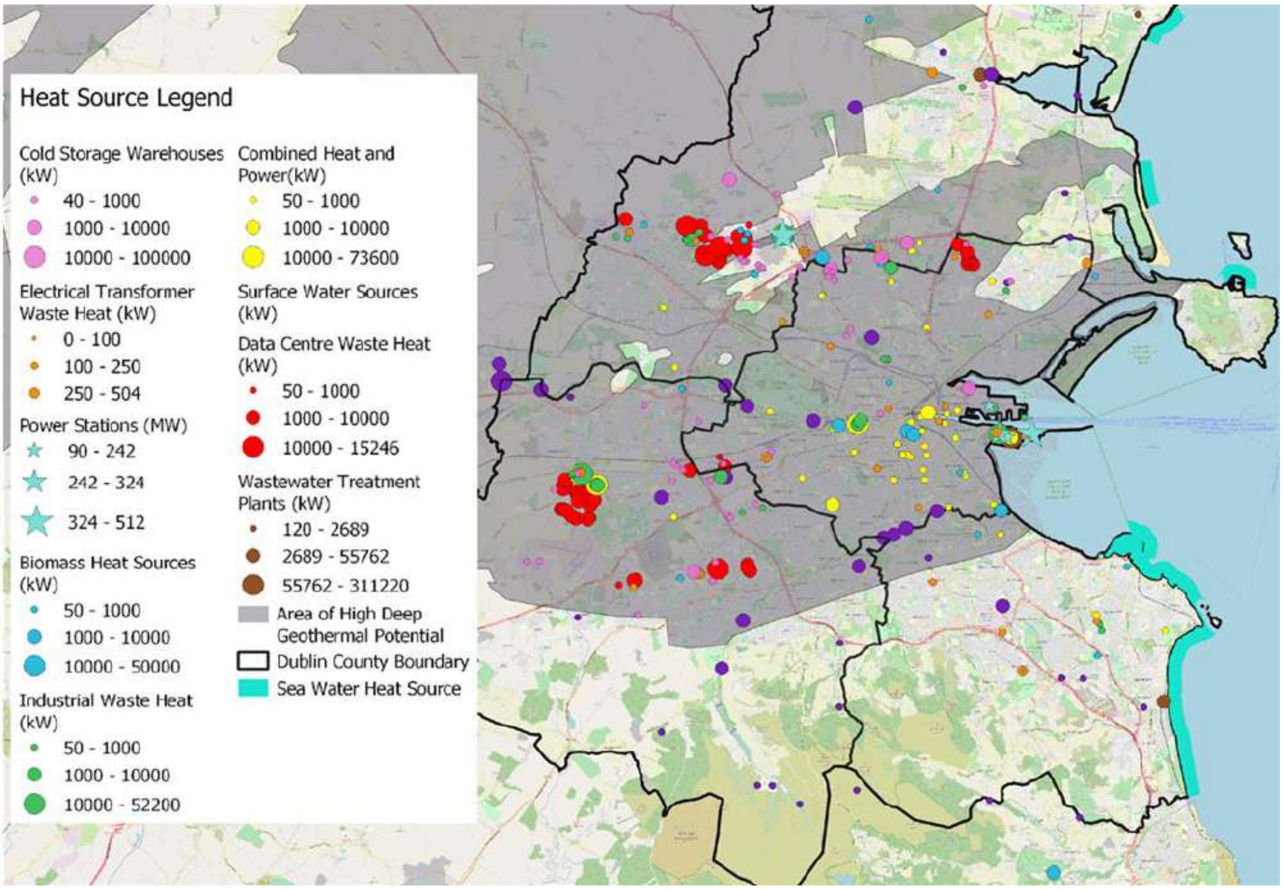

Figure 48: Map of Heat Sources for Dublin

The graph on the next page shows the typical temperature ranges for common heat sources, which can be utilised via district heating networks. The right hand side of the graph also shows typical end-use temperature requirements. In the cases where the source temperature needs to be increased in order to provide heat at a usable temperature for its end use, heat pumps are commonly used. On the left hand side of the graph the heat pump efficiency (coefficient of performance) is shown when raising the source temperature to either 60°C or 80°C, which are common supply temperature ranges for DH networks which utilise heat pumps. It should also be noted that the temperature requirement for an end use will have to be increased by typically 3 - 5°C for every hydraulic break between the source and the end use (e.g. heat exchangers, HIUs).

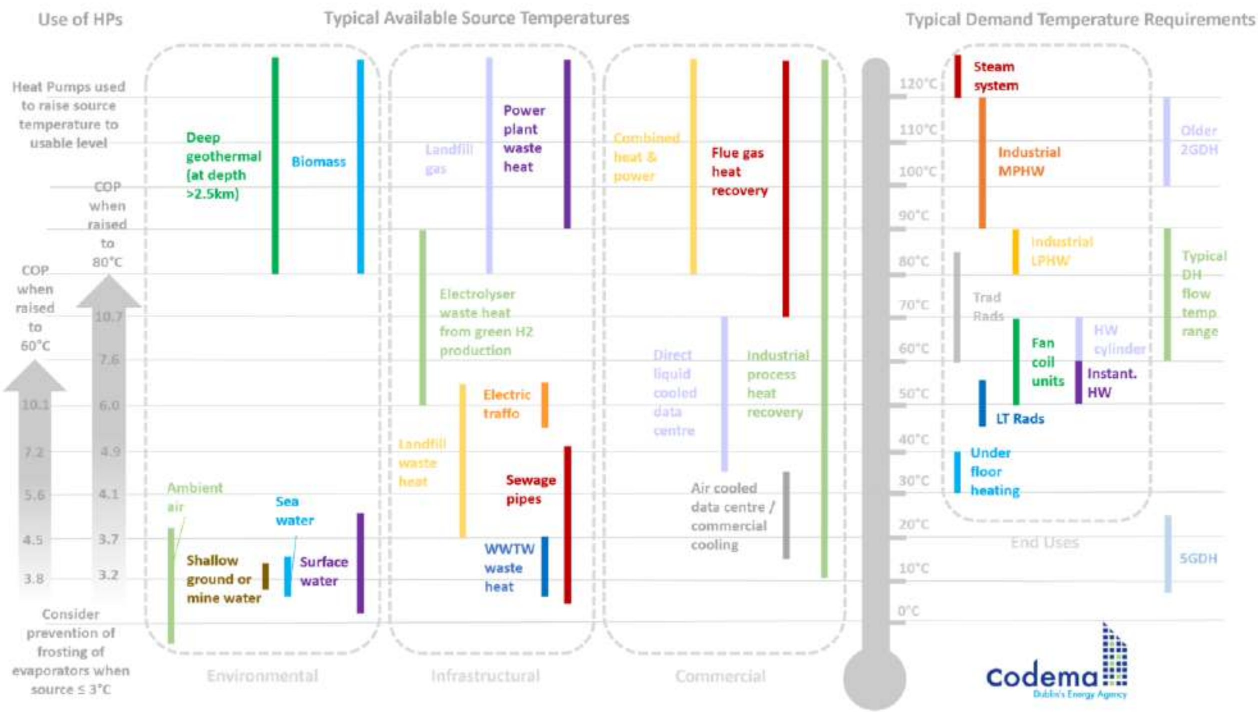

Figure 49: Typical heat sources temperatures and required end uses temperatures

Heating Pathway

This section shows the results of the heat analysis. The map below shows the preferred heat decarbonisation option for each small area based on the above analysis and resulting €/tCO_2 abatement cost over the period up to 2030 and 2050. This analysis includes savings from both CO_2 emissions (combusting fuels, consuming electricity) and CO_2 equivalent emissions (methane leaks, refrigerant leaks, NOx emissions). The costs included in this analysis include capital expenditure, replacement expenditure (annualised based on the technologies' expected lifespan) and maintenance costs. The particulate matter (PM) emissions from combustion heating systems which have an impact on local air quality and citizen health are translated into a health impact cost in the Socio-Economic Impact chapter.

It should be noted that for the purpose of this analysis, it is assumed that DH heat price to customers is equal to the counterfactual (boilers and heat pump heat prices). This is a conservative estimate as in reality the DH heat price is likely to be 5 - 10% lower than the alternative heating technology. Unlike HPs, DH can operate efficiently without the need for building fabric upgrades, however, building fabric upgrades have been assumed for both scenarios in line with a "fabric first" approach to deliver energy efficient buildings within the region. The fabric upgrades were adopted to reach threshold u-values on the three main building fabric elements (external walls, windows and roofs).

The figure on the next page shows the areas most suited to each technology up to 2030. The areas coloured blue are most suited to heat pumps and the areas coloured red are most suited to district heating. The darker the colour, the more suited that area is to either technology.

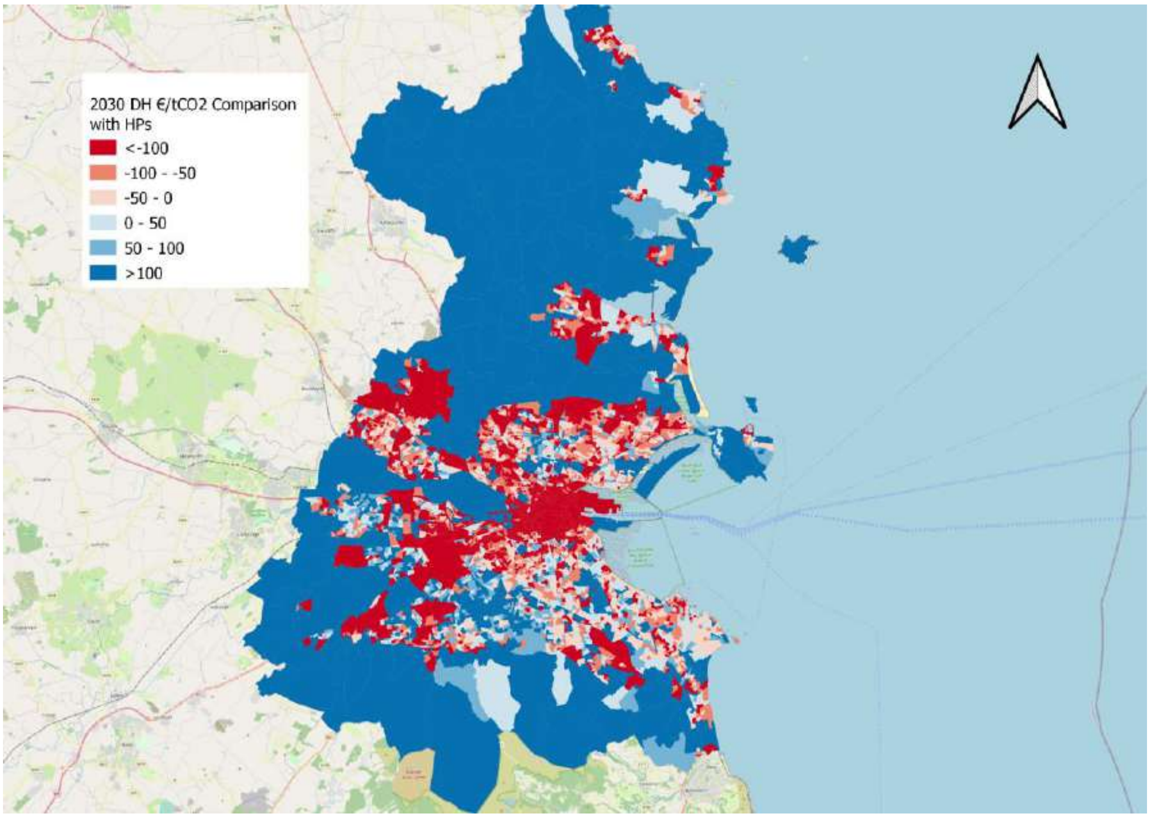

Figure 50: 2030 DH and HP priority areas based on lowest non-discounted carbon abatement cost

District heating represents the best option for 7.43TWh of heat demand in terms of cost-effective decarbonisation, which would save 1,441.7ktCO_2 in the year 2030. However, like other technologies, the supply chain needs to be developed in order to deliver on this potential. The current national government target of 2.7TWh by 2030 reflects the supply chain growth experienced by other countries when they first began adopting DH in the 1970s. As Dublin is more advanced in the planning and development of DH systems, it is fair to assume that the majority of this target will be met by Dublin and so this was used as a reasonable interim regional target for 2030. This 2.7TWh would save 502ktCO_2 in carbon emissions and save 172.8kT$CO^2_{eq.}$ in equivalent emissions in the year 2030. The map on the next page shows the areas where DH could be first adopted (i.e. is most cost-effective) to reach this 2.7TWh target.

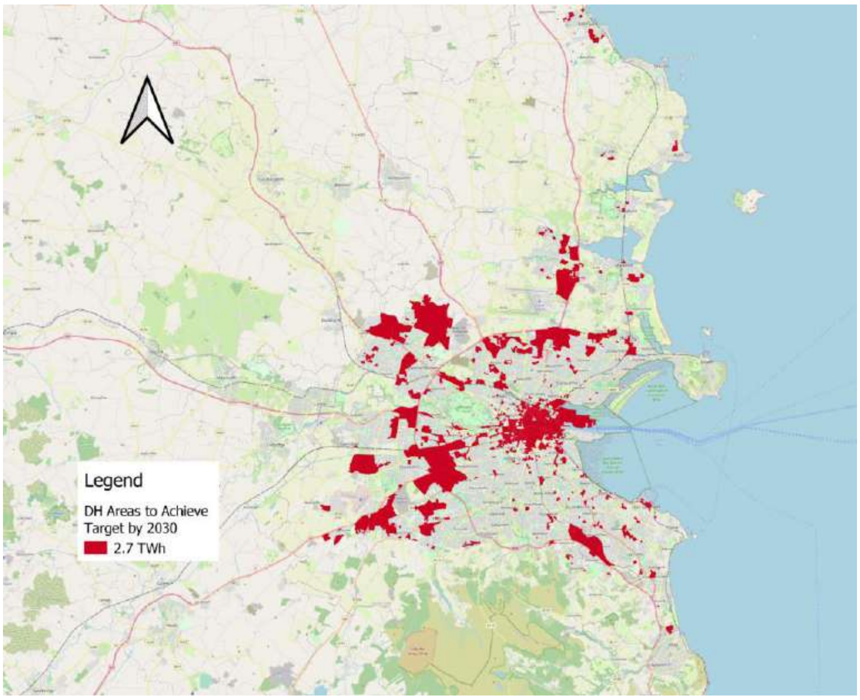

Figure 51: Priority DH areas for achieving 2.7TWh target by 2030

The 2.7TWh target for 2030 would require 376.3km of distribution pipework and 774.5km of customer connections estimated to cost €980.4 million. The total capital cost of achieving this target is estimated at €1.1 billion with the majority of this investment staying within the local economy. This would create the equivalent of 2,281 direct local jobs per year for this period to 2030.

The figure on the next page shows the areas most suited to each technology up to 2050. The areas coloured blue are most suited to heat pumps and the areas coloured red are most suited to district heating. The darker the colour the most suited that area is to either technology. It can be seen from this map that the areas suited to DH have increased over the period 2030 to 2050. The main reason for this is that the up-front capital investment in the network infrastructure is recouped over a longer period in this scenario. It is worth noting that this effect will continue beyond 2050 making DH an even better solution over time.

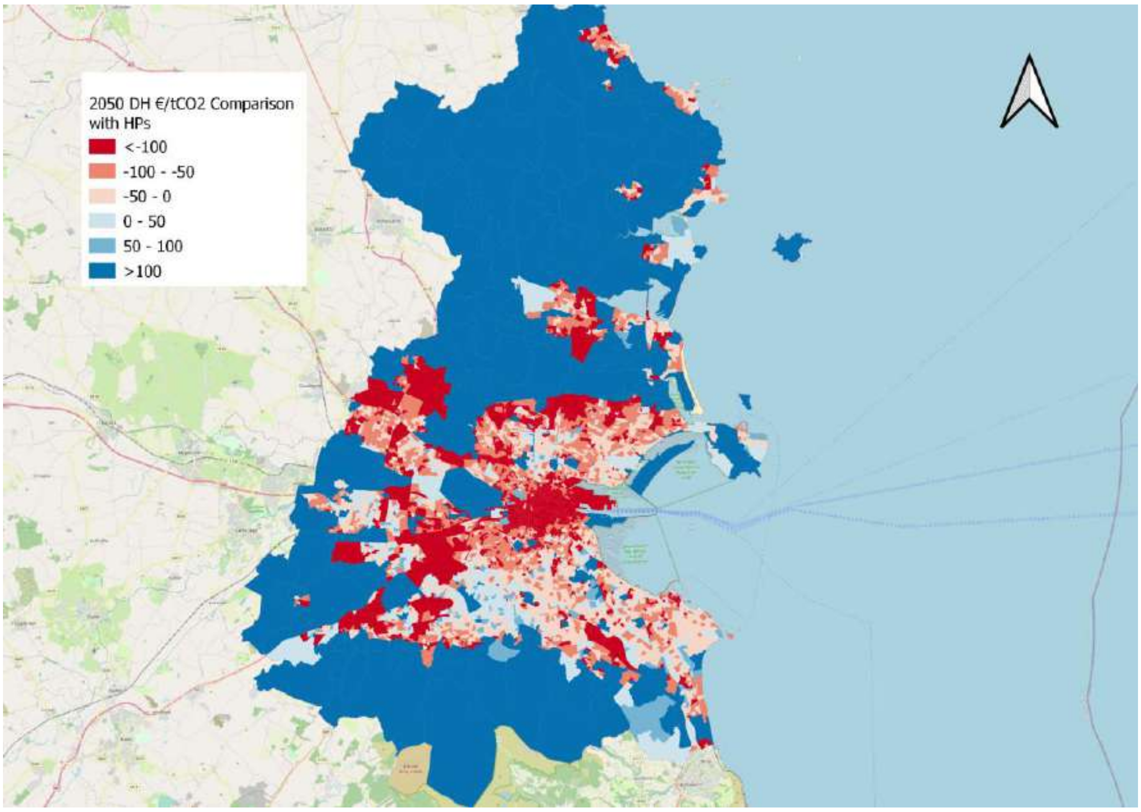

Figure 52: 2050 DH and HP priority areas based on lowest non-discounted carbon abatement cost

By 2050, district heating represents the best option for 9.06TWh of heat demand in terms of cost-effective decarbonisation. By 2050, it is assumed that the required supply chain is in place to deliver on the full DH potential outlined. This would save 1,550.1ktCO_2 in carbon emissions and 617.6kTCO_2eq. in equivalent emissions in the year 2050.

This DH roll out optimised to 2050 would require 2,421.8km of distribution pipework and 4,209.5km of customer connections, estimated to cost €5.7 billion. The total capital cost of achieving this target is estimated at €7.7 billion with the majority of this investment staying within the local economy. This would create the equivalent of 4,354 direct local jobs per year for the period 2021 to 2050.

Heat pumps represent the best option for 93,362 buildings (6,845 commercial and 86,517 residential dwellings) in 2030 saving 503.9ktCO_2 and 165ktCO_2 equivalent. However, this drops to 78,128 buildings by 2050 due to the increased competitiveness of the DH networks over a longer time span (due to the network lifespan being in excess of 50 years compared with a 15 year lifespan for an individual heat pump). The total capital cost of installing 78,128 heat pumps (excluding the building fabric upgrades) is €1.2 billion. This would create the equivalent of 382 direct local jobs per year[69] for the period up to 2050. These individual heat pump installations would cover 1.27 TWh of heat demand in 2050 and save 233.1 ktCO_2 and 80.9 ktCO_2 equivalents.

In order to avoid double counting of carbon savings, the fabric upgrade savings are calculated based on the assumption that the aforementioned technology adoptions take place - full adoption of both DH and HPs by 2050 and the interim targets met by 2030 (i.e. 2.7TWh DH and 78,128 heat pumps). These figures are based on 317,577 homes undertaking some level of retrofit by 2030 (166,966 external wall retrofits, 18,360 roof retrofits and 314,533 window retrofits). This would save 206.3ktCO_2 in 2030 but once the other heating technologies are adopted by 2050 this saving drops to zero. The reason for this drop is that the only fuel used by the heating systems outlined in this analysis would be zero-carbon electricity to drive the pumps for collecting waste heat, geothermal heat, etc. or for heat pump compressors where heat pumps are required to increase water temperatures. It should be noted that the additional benefits of increased comfort and efficiency delivered by retrofitting are considered an important feature of the “fabric first” approach

[69] Assuming the 30% of the cost for install stays within the local economy

adopted despite their value for money in terms of carbon abatement being lower than the heating technologies investigated (average abatement cost for these fabric upgrades is estimated at €3,127/tCO_2). In the case of DH, the efficiency gains of this fabric first approach are not as pronounced and therefore shallower or no retrofitting may be required in these areas but should be assessed on a case-by-case basis.

Table 3: Carbon and Energy Savings Summary Table for Heating Pathway

		2030	2050
CO_2 Savings (ktCO_2)	**Dwelling Fabric Upgrades**	206.3	0.0
	District Heating	502.0	1550.1
	Heat Pumps	503.9	233.1
CO_2 Equivalent Savings (ktCO_2 eq.)	**Dwelling Fabric Upgrades**	46.9	0.0
	District Heating	172.8	617.6
	Heat Pumps	165.0	80.9
Heat Demand Supplied or Saved (TWh)	**Dwelling Fabric Upgrades**	1.1	1.1
	District Heating	2.7	9.1
	Heat Pumps	2.6	1.3
	BaU Heating Technologies	4.7	0.0

Electricity

In order to facilitate a transition to cleaner electricity generation, Codema investigated the potential of utility-scale solar photovoltaics (PV), building integrated rooftop solar PV and onshore and offshore wind development in Dublin. Despite the lack of existing operational sites in Dublin, there is significant potential across all technologies summarised in the table below.

Table 4: Renewable electricity generation and carbon saving potential in Dublin

Technology	GWh		tCO_2 Saved	
	2030	2050	2030	2050
Utility-Scale Solar PV	854	1,057	277,124	343,036
Onshore Wind	130	325	42,163	105,572
Offshore Wind	5,241	13,124	1,700,768	4,258,600
Building-Integrated Solar PV	84	270	27,237	87,763
Curtailment Assumed Avoided by EV+DH	462	2,421	149,892	785,551
Total	**6,309**	**14,776**	**2,047,292**	**4,794,972**

The potential for renewable electricity generation in Dublin is investigated in this section of the report. In order to determine the cost of developing this potential, the following levelised cost of energy (LCOE) figures[70] were used. This is also sometimes referred to as the life-cycle cost (LCC). The LCOE is a way of comparing generator technologies and considers the capital and operational costs of the technology. The LCOE figures used in this assessment are set out below. This has been combined with the carbon saving potential of these technologies when compared with the current generation mix to give a carbon abatement cost as shown in the table below.

Table 5: Carbon abatement costs for renewable electricity generating technologies

Technology	€/MWh	€/tCO_2 Abated
Offshore Wind	65.6	-55.0
Onshore Wind	52.9	-94.0
Utility-Scale Solar PV	50.6	-101.1
Closed-Cycle Gas Turbine	97.8	N/A
Open-Cycle Gas Turbine @ 500 hours	228.9	N/A
Open-Cycle Gas Turbine @ 2000 hours	157.6	N/A
Building-Integrated Solar PV	131.1	147.0
Current Generation Mix (2019)	83.4	N/A

Solar Photovoltaics

Photovoltaic (PV) cells convert solar radiation directly into DC electricity. PV uses energy from light to create electricity; when light shines on a PV cell, it creates an electric field across the layers causing electricity to flow. Individual PV cells only provide a small amount of electricity, so they are generally grouped together into a module for convenience. PV is generally more suited to areas where the electricity generated can supply a nearby load, and the energy loss and costs associated with transmission and distribution are avoided.

The potential generation capacity of building-integrated PV across Dublin rooftops, along with adopting utility-scale solar PV (USSPV) on all areas of land deemed suitable, has been calculated at 270 GWh and 1,057 GWh respectively. If all these projects were implemented this would translate to a total CO_2 saving of 430,800 tonnes per year.

Wind

Wind energy is produced primarily through wind turbines, which harness the wind to provide mechanical power to a generator to produce electricity. Wind turbines are a key technology in the decarbonisation of the electricity sector and

70 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/911817/electricity-generation-cost-report-2020.pdf

are by far the largest renewable electricity generating method in Ireland, representing almost 40% of total electricity generation. The national target for renewable electricity is to have 80% renewables by 2030. It is envisaged that wind power will continue to play a leading role in meeting this target.

Two main subcategories of wind generation have been investigated in this report. The first of these is onshore wind where wind turbines are installed on land, usually in upland areas where wind speeds are higher and where they are a sufficient distance from existing buildings. The second is offshore wind where the turbines are installed offshore in relatively shallow waters. The criteria used for identifying suitable areas for the adoption of onshore wind are discussed in greater detail in Appendix D of this report.

The electricity grid

The electricity grid is the name given to the network of electrical cables, transformers etc. which are used to transport electricity from where it is produced to where it is used. These networks have capacity limits above which additional electricity transfer would cause thermal overload and damage the network. In order to avoid this, the grid either needs to keep the maximum electricity load it needs to transfer within its maximum limit or it need to be upgraded (or reinforced) to be able to carry additional load.

In the decarbonisation pathway outlined the additional investment required for the electrification of heat and transport has been accounted for with these technologies through the use of a €/kW$_e$ cost calculated from ESB standard connection upgrade costs. This is discussed in greater detail in Appendix D of this report. The average cost per kW is also adjusted for different zones within Dublin in order to reflect the real world grid constraints shown in the map below.

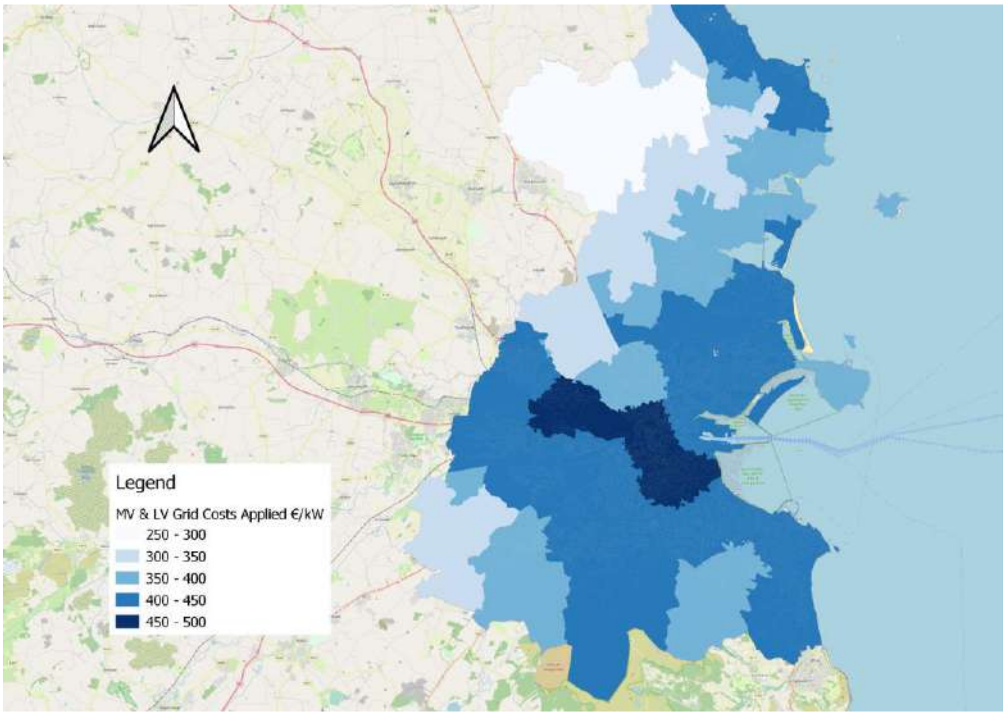

Figure 53: Map showing variations in electrical grid upgrade costs across Dublin

Transport

The scope of Transport energy demand and emissions covered in this analysis extends only to land-based transportation. This excludes two major sectors: aviation and maritime transport. These have been excluded on the basis that international aviation and maritime navigation are not counted as part of Ireland's national emission inventory, as prepared by the EPA. A substantial proportion of Irish aviation emissions are accounted for under the EU ETS system, but maritime transport is currently not subject to any emission targets or policies within the EU. The extension of the EU ETS to cover maritime transport has been proposed under the EU's Green Deal initiative. These two sectors will be particularly hard to decarbonise over the coming decades, as battery electrification does not currently have the required energy density to replace liquid fossil fuels, adding too much weight to the systems. Green hydrogen and hydrogen-based synthetic "e-fuels" are expected to be the main tools in the decarbonisation strategies of these sectors.

Transport Policy

Due to the complexity of the Transport sector, there is no single 'silver bullet' solution to reduce energy demand and emissions from the land-based transport systems. The required cuts in emissions can only be achieved through a combination of different approaches. In March 2021, the Government's Five Cities Demand Management Study Recommendation Report was published. This report evaluated numerous local and national policy measures which could be taken to achieve reductions in transport demand in the five largest cities in the country (Dublin, Cork, Waterford, Limerick and Galway). This report made the recommendation that the internationally recognised 'Avoid-Shift-Improve' approach needs to be firmly embedded within our transport and mobility infrastructure planning in order to address the congestion, GHG emissions, local air quality and overall urban environment issues associated with transport.[71] This approach was similarly recommended in June 2021 by the Oireachtas Joint Committee on Environment and Climate Action in its 'Report on Reducing Emissions in the Transport Sector by 51% by 2030'.[72] With this approach, the priority should firstly be to avoid the need for travel, thus avoiding the creation of transport emissions in the first place. If travel cannot be avoided, then the mode of travel should be shifted away from energy and carbon intensive modes to more sustainable, zero- or low-carbon modes. If no alternative, more sustainable modes of transport are available, then the last resort should be to improve the energy efficiency and reduce emissions of existing modes through technological advancements. The following table outlines the main avoid-shift-improve strategies considered in developing this masterplan.

Table 6: Avoid-Shift-Improve strategy and potential solutions

Strategy	Solutions
Avoid:	Integrated spatial planning
	Remote working and hubs
	Review of road construction projects
Shift:	Walking and cycling
	Personal e-mobility (e.g. e-bikes, e-scooters)
	Cargo bikes
	Rail freight
	Public transport
Improve:	Freight logistics planning
	Overhead catenary/electric road direct electrification
	Battery electrification
	Hydrogen fuel cell electrification
	Biofuel blending

The National Planning Framework 2040 sets out a number of spatial planning policies aligned with the 'avoid' principle. This includes the target that at least 50% of all new housing in Dublin should be built within the existing urban footprint of the county. It states that safe, convenient and universally accessible alternatives to car travel should be central to any development. Walking and cycling accessibility must be prioritised, both within any new development and between other existing developments. This policy document also states that any further population growth outside the existing city and its suburbs should be in the form of compact developments, served by high-capacity public transport networks and related to significant employment provision. These policies are further strengthened for Dublin and the

[71] https://www.gov.ie/en/publication/63517-publication-of-five-cities-demand-management-study-phase-1-report-and-toolkits/

[72] https://www.oireachtas.ie/en/press-centre/press-releases/20210603-joint-committee-on-environment-and-climate-action-launches-report-on-reducing-carbon-emission-in-transport-sector-by-51-by-2030/

surrounding counties in the 2019-2031 Regional Spatial and Economic Strategy (RSES), prepared by the Eastern and Midland Regional Assembly.

The prevalence of remote working has seen a huge increase as a result of the Covid-19 pandemic. This initially led to huge decreases in the number of vehicles on our roads as many people no longer had long commutes to make. Transport Infrastructure Ireland's traffic count data suggests that although traffic volumes have since recovered significantly, the number of cars travelling into Dublin at morning rush hour are still 10-20% lower than on the same day in 2019.[73] As we emerge from this extended period of enforced remote working, it is expected that much more flexibility will be afforded to office workers to work remotely from now on. While some employers have told staff that they never have to return to the office, for most it would appear that two or three days a week in the office at least will become standard practice. The Right to Request Remote Work Bill is due to be enacted in 2022, and will give employees a legal right to request remote working. A recent study found that over 58% of workers living in Dublin and directly surrounding counties could have the potential to work from home, based on their sector of employment.[74] Enabling even a portion of these workers to work remotely could have a significant impact on transport emissions from commuting, although a rebound effect should be expected in increased home heating demands. Remote working hubs could provide a good balance between office space requirements, reduced commuting distances, and efficient space heating systems, particularly in outlying or more rural parts of the county.

The Transport Strategy for the Greater Dublin Area 2016-2035 notes that due to heavy congestion, policy since the 1990s has been not to increase private car capacity on radial roads inside the M50, and instead to try to optimise the use of the limited road space between the various competing modes of transport. It is well understood now that widening busy roads will only achieve a temporary improvement in traffic congestion, and will ultimately lead to increased external costs on society and higher emissions.[75] This concept is known as 'induced demand', and is the inverse of the 'traffic evaporation' concept described earlier in this report. While the provision of increased car capacity will initially ease congestion and reduce travel times, gradually people will change their behaviour to take advantage of this, until traffic levels have returned to their previous congested state, but now with higher energy demand and associated emissions. In spite of this, multiple road widening and capacity enhancement projects were included for the main arterial roads into Dublin, as well as the M50 itself, as part of the 2016-2035 GDA Transport Strategy, and have been carried through to the Draft 2022-2042 strategy. In some cases, road widening has been justified by the need to provide dedicated bus lanes; however, if a significant level of modal shift and corresponding reduction in emissions is being targeted, then just like inside the M50, a reallocation of the existing road space is a far more appropriate solution. As such, a detailed review of all planned road capacity enhancement schemes in the Dublin metropolitan area should be undertaken in order to assess their individual and cumulative impact in terms of GHGs and our new and more challenging national targets. This may prevent the need for more punitive emissions reduction measures later in this decade, such as per-kilometre road charging or fuel rationing for private vehicles.

The 'shift' to and prioritisation of active travel and public transport has been clearly set out in Government policy since the publication of Smarter Travel: A Sustainable Transport Future in 2009. This emphasis was further strengthened in the urban context with the publication of the Design Manual for Urban Roads and Streets (DMURS) in 2013, and revised in 2019. To assist in the design of cycle-specific infrastructure, the National Cycle Manual was published in 2011, and is due for a major revision in 2022, in line with developments in international best-practice for providing safe, comfortable, prioritised and attractive cycling routes. DMURS sets out the following chart, which designates the user hierarchy that must be adhered to when urban areas and streets are being designed to *'encourage more sustainable travel patterns and safer streets'*. The DMURS manual applies to all roads or streets with a speed limit of 60 km/h or less, so it is particularly relevant for the largely built-up county of Dublin. It also stipulates that the principles of universal design should be incorporated into urban design, ensuring accessibility for all ages and abilities.

[73] https://www.tii.ie/news/press-releases/?page=1
[74] https://www.ucc.ie/en/media/projectsandcentres/srerc/COVID19_FC_JD_2020_website.pdf
[75] https://www.vtpi.org/gentraf.pdf

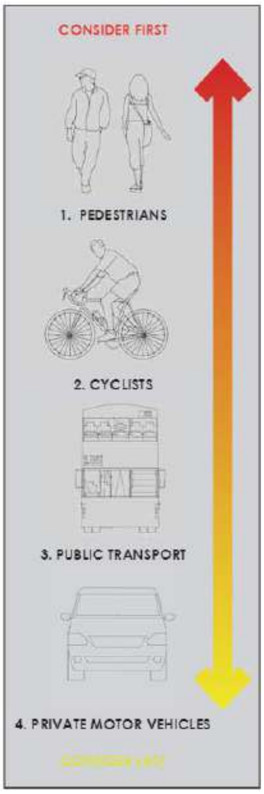

Figure 54: User hierarchy to be considered in urban areas (Source: Design Manual for Urban Roads and Streets, Government of Ireland, 2013[76])

Specific goals and targets for Dublin's transport system have been set out in the NTA's Transport Strategy for the Greater Dublin Area 2016-2035. A 2022-2042 update to this strategy was published in draft format in late 2021; however, the analysis completed in this masterplan was completed prior to publication of this draft, and is based on the 2016-2035 strategy. This 2016-2035 strategy sets out timelines for a number of major public transport infrastructure projects, including DART expansion, Metrolink, BusConnects and Luas expansion.

Existing national and regional transport policy is strongly focussed on passenger transportation, rather than commercial or freight transportation. The focus has mostly been on commuter journeys to work or education, and trying to reduce traffic congestion at peak times from an economic viewpoint. In 2017, the Department of Transport, Tourism and Sport estimated that the cost of lost time due to 'aggravated' congestion was €358 million, and could rise to over €2.1 billion per year by 2033 if left unaddressed.[77] Tackling the peak commuter periods only partially addresses the issues around sustainable mobility, with trips to work or education only accounting for 26% of all journeys taken nationally in 2019.[78] This share is likely to have dropped significantly due to Covid-19 and the resulting accelerated transition towards remote or blended working, so the focus of transport policy now needs to be rebalanced accordingly. While high-capacity commuter services to the city centre will still be required into the future, attention needs to be turned towards the other trip types, with an increased focus on local trips. There is huge scope for energy and emission reductions by shifting from car to active travel for local trips, with 57% of all trips of less than 2 km and 73% of trips between 2-4 km currently undertaken by car nationally.[79] Recent research conducted by University College Cork's Energy Policy and Modelling Group found that 37% of all passenger travel emissions nationally come from trips of under 8 km.[80] In Dublin, almost three out of every four trips are less than 8 km.[81] If safe and convenient infrastructure was available, a significant number of these trips could be carried out by walking, rolling, cycling or alternative low-carbon e-mobility options.

76

77 https://www.gov.ie/en/publication/679669-cost-of-congestion-main-report/

78 https://www.cso.ie/en/releasesandpublications/ep/p-nts/nationaltravelsurvey2019/

79 https://www.cso.ie/en/releasesandpublications/ep/p-nts/nationaltravelsurvey2019/

80 https://www.sciencedirect.com/science/article/pii/S1361920922000268

81 https://www.cso.ie/en/releasesandpublications/ep/p-nts/nationaltravelsurvey2019/

Transport Modelling

The chart below provides an indicative breakdown of the current carbon emissions from various urban transport modes, per passenger-kilometre travelled. This provides a general idea of the modes that should be considered for prioritisation, with data specific to Dublin or Ireland used, where available. This chart includes both direct and indirect GHG emissions from transport fuels - i.e. the tailpipe emissions from combustion engines and the emissions from the generation of electricity consumed in transportation, using the 2019 national average electricity emissions factor. It does not, however, consider the full lifecycle GHG emissions relating to each mode. The occupancy levels of each mode have a significant impact on the emissions below. For cars, this chart assumes an average occupancy of 1.5 people.[82]

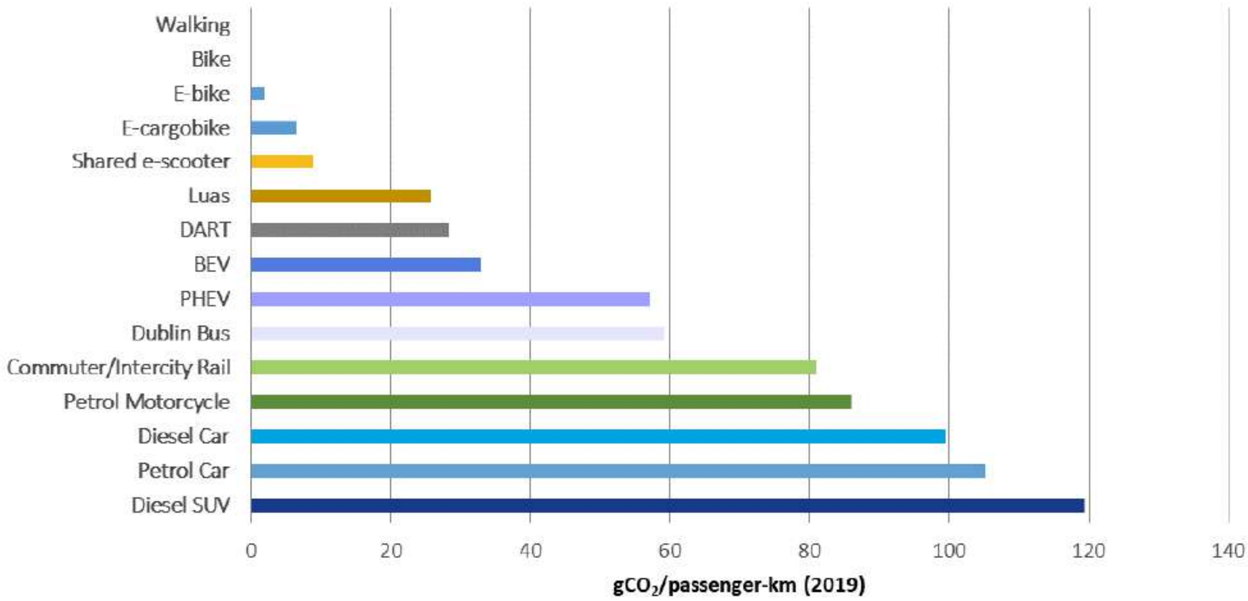

Figure 55: CO_2 emissions per passenger-km by vehicle type in Ireland 2019

Figure 55 presents the same modes of transport, however, the data has been revised to represent projected emissions in 2030. The difference between fossil fuel and electric vehicles is much clearer in this case, due to the significant reduction in carbon emissions from electricity generation expected by 2030. By this point in time, most public transport in Dublin will be electric, marking a huge decrease in emissions per passenger-km for those fleets currently powered by diesel. PHEVs stand out in this chart, achieving relatively little reduction in emissions compared to fully electric modes over this period.

[82] Based on UK data: https://www.gov.uk/government/statistical-data-sets/nts09-vehicle-mileage-and-occupancy

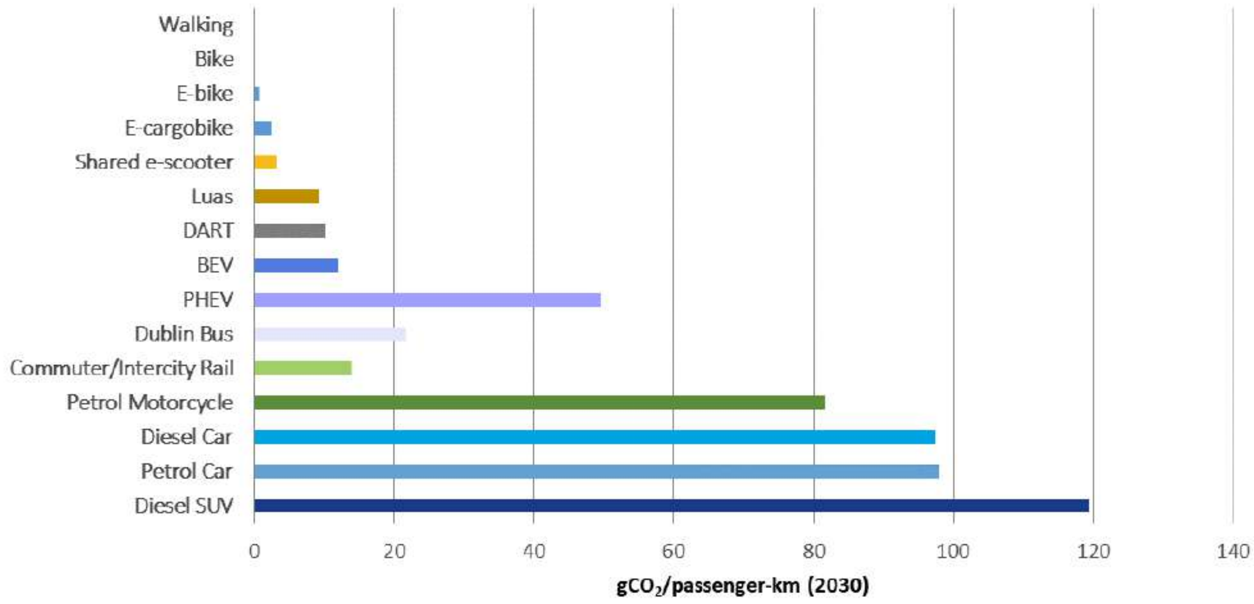

Figure 56: CO_2 emissions per passenger-km by vehicle type in Ireland 2030

As noted above, these charts do not tell the full story, as embodied energy and emissions resulting from manufacturing, maintenance and disposal of vehicles (referred to as 'Scope 3' emissions) can often outweigh the lifetime operational energy demand and emissions. Manufacturing and disposal tend to represent a higher proportion of lifetime emissions for battery electric modes, and for modes with short lifetimes or which travel relatively short distances over their lifetimes.[83] For example, a shared e-scooter may have an operational life of just 12 months and travel less than 5,000 km over its lifetime, compared to a DART carriage which may last up to 40 years and travel millions of kilometres over its life.

In order to model the operational road transport energy demand and emissions in Dublin, Codema used outputs of detailed modelling carried out by the National Transport Authority (NTA). The NTA provided outputs from their East Regional Model (ERM) for two scenarios, the base year of 2016 and a future projection to 2028, which was based on the implementation of the main projects outlined for this period in the NTA's Transport Strategy for the Greater Dublin Area 2016-2035. The ERM covers the entire East of the country, but for Codema's analysis only the trips that were carried out either partly or fully within the boundaries of County Dublin were selected for inclusion. The NTA provided data in the form of a GIS map made up of "links" representing the road network in Dublin. Each link had a set of emissions values attributed to it, calculated based on the traffic makeup and volumes expected along it.

Unfortunately, the NTA's environmental model was not designed to provide detailed energy data outputs alongside this emissions data, so energy demand had to be calculated using another method. This was done using the corresponding vehicle-kilometres data, which gave the total distances travelled by each of the main road vehicle classes in the NTA's model: car (including taxis), van/light goods vehicle (LGV), truck/heavy goods vehicle (HGV) and bus. This data related to a typical midweek day, and was converted to annual figures based on results gathered as part of the 2017 National Household Travel Survey. Using standard emissions factors, these annual vehicle-km figures could be used to generate estimates of energy demand and emissions from each vehicle class for both the base year of 2016 and also 2028. This data was available at an overall county-wide level only, and so unfortunately no spatial analysis was possible.

Road vehicle-km projections were produced for each vehicle class out to 2030 and 2050. For 2030, the NTA's 2028 figures were extrapolated based on the average annual rate of change between their 2016 and 2028 model runs. The projections to 2050 were based on the assumption that the level of transport demand within the county from 2030 to 2050 would be directly proportional to its population. Future population estimates generated by the ESRI were thus

[83] https://tnmt.com/infographics/carbon-emissions-by-transport-type/

used to extrapolate future road vehicle-km figures out to 2050 for each vehicle class. Total projected annual vehicle-km figures for the Business-as-Usual scenario are presented below. It can be seen that a 9% reduction in car vehicle-km is projected for 2030 compared to the base year, although increases were projected in LGV, HGV and bus vehicle-km. These figures were used as the basis for the three scenarios modelled for transport, as described later in this section.

Table 7: Annual vehicle kilometres for Business as Usual scenario

	Current	2030	2050
	Annual Vehicle-kilometres (million km)		
Car	6,408	5,804	6,234
LGV	797	1,145	1,230
HGV	330	499	536
Bus	73	95	102

The outputs provided by the NTA's ERM model did not include any emissions from either light or heavy rail in Dublin, although the impact of these modes on road transport was modelled. A simple rail model was built by Codema, which estimates energy demand and emissions along each section of track within the county. These figures were calculated by taking into account the length of each section of track, the frequency of services along the track, and the specific energy demand and emissions from each rail vehicle type, per kilometre travelled. Future rail projects as outlined in the 2016-2035 Greater Dublin Area Transport Strategy were taken into account in both the 2030 and 2050 projections as appropriate.

Combining all of the road and rail transport emissions, an overall picture of the transport sector could be developed. A breakdown of the total emissions by vehicle type is presented below. As noted previously, the indirect emissions related to the generation of electricity are included in all transport emissions figures in this analysis. This mostly relates to rail transport in the current situation, but will have an increasingly important effect as the transport system electrifies out to 2050. It has been assumed that the national electricity supply system will be completely decarbonised by 2050.

It can be seen that cars account for almost two thirds of current transport emissions in Dublin, while commercial road vehicles make up the second largest proportion at 27%. A surprisingly low proportion is attributable to public transport, which reflects decades of delays and underinvestment in these sustainable modes. Combined with poor spatial planning, this has induced further car traffic volumes and created a society based around car dependency. It is clear that significant actions will be required to address this imbalance in favour of more sustainable options such as walking, cycling and public transport. Reducing car activity will also bring many co-benefits other than just reduced GHG emissions. These include safer streets with more space for people, healthier communities and more equitable access to mobility for all residents of Dublin.

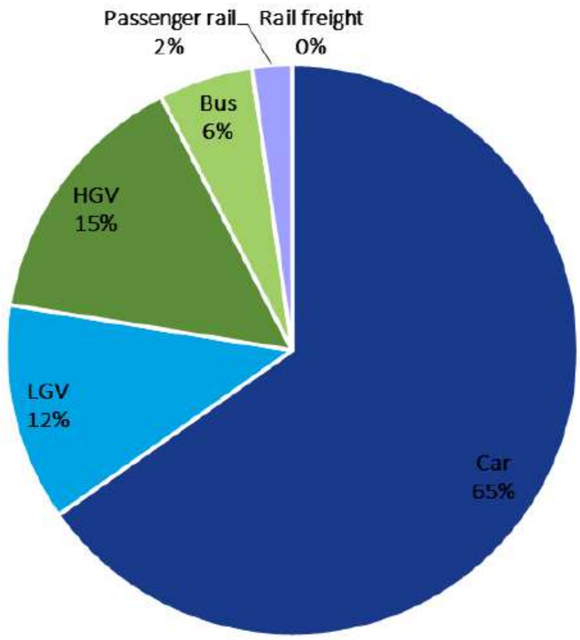

Figure 57: Current transport emissions by mode

Looking beyond the current picture, three future scenarios were developed for Dublin's transport-related energy demand and emissions, as described in the following sections. These ranged in ambition from a do-nothing "Business-as-Usual" scenario, all the way to a fully decarbonised transport system by 2050, which would also achieve a 51% reduction in emissions by 2030. A medium ambition scenario was also explored, based on the policies and actions outlined in the Government's Climate Action Plan 2019.

Business-as-Usual Scenario

The Business as Usual (BaU) transport scenario built on previous work carried out by University College Cork and MaREI researchers in their 'Irish Car Stock Model (v2.4)'.[84] The key assumption was that the share of new car sales by fuel type would remain constant from 2018 to 2050. In this scenario, the annual new car sales shares of PHEVs, mild hybrids and BEVs would account for approximately 1%, 5% and 1% respectively, with the remaining 93% of sales either petrol or diesel fuelled. This represents a worst-case scenario, considering the significant increase in sales of these vehicle types over the past 3 years. National average CO_2 emissions and energy demand values from this model were applied for Dublin's car stock, from the 2018 base year out to 2050. These values were modified slightly to include a higher assumed energy demand from BEVs of 15 kWh/100km, which is still probably somewhat optimistic given the recent trend towards heavier SUVs. Another major assumption was that the level of biofuel blending in petrol and diesel would remain static at 6% and 7% respectively. For 2030 and 2050, it was assumed that all other road transport would remain diesel fuelled. Rail transport was modelled in line with the projects outlined in the 2016-2035 Greater Dublin Area Transport Strategy.

The results of this analysis can be seen in the tables below. It can be seen that both energy demand and emissions both increase to 2030 and again to 2050. This is due in large part to the projected increase in population of the county of 9% by 2030 and 17% by 2050, compared to 2020.

[84] https://github.com/vor115384876/Irish-Car-Stock-Model

Table 8: Business as Usual Current, 2030 and 2050 Annual Emissions

Business as Usual	Current	2030	2050
	Annual Emissions (tCO_2)		
Car	1,085,234	917,950	986,108
LGV	205,014	294,474	316,339
HGV	247,092	374,547	402,357
Bus	88,953	115,201	123,755
Passenger rail	37,174	42,627	55,113
Rail freight	239	239	239
Total	**1,663,707**	**1,745,038**	**1,883,911**
% change		**5%**	**13%**

Table 9: Business as Usual Current, 2030 and 2050 Annual Energy Demand

Business as Usual	Current	2030	2050
	Annual Energy (TWh)		
Car	4.0	3.643	3.914
LGV	0.8	1.100	1.182
HGV	0.9	1.399	1.503
Bus	0.3	0.437	0.469
Passenger rail	0.1	0.139	0.178
Rail freight	0.0	0.001	0.001
Total	**6.2**	**6.719**	**7.247**
% change		**9%**	**17%**

Scenario A - Climate Action Plan 2019

Scenario A was based on the BaU Scenario, and added the main policies and targets set out in the Government's Climate Action Plan 2019. This plan focused largely on electrification of vehicles, with an overall target of 936,000 electric vehicles nationally by 2030. Specific targets for cars, commercial vehicles and buses were included in the plan, which have been scaled down proportionally to Dublin based on the numbers of each vehicle type currently licensed in the county. This resulted in 213,000 electric cars, 16,065 electric LGVs and 1,760 electric HGVs. It should be noted that in all of the analysis carried out in this Masterplan, Codema only considered fully-electric BEVs as 'electric', and counted all hybrid vehicles, including PHEVs, as fossil fuel vehicles. The reasoning behind this is explained later in the 'Challenges and Barriers' section of this report. For buses, the slightly more ambitious targets published under the BusConnects programme for Dublin were used. This sets out that by 2035, all urban public buses operating within the Dublin Metropolitan Area will be zero (tailpipe) emission vehicles. For 2030, it was assumed that 50% of the public bus fleet would be electric. The biofuel blend in petrol and diesel was also increased to 10% and 12% respectively by 2030, as set out in the CAP 2019. No further modal shift was factored in, beyond that already accounted for in the NTA's 2028 projections.

For 2050, it was assumed that all cars would be electric, in line with the proposed sales ban on internal combustion engine (ICE) cars after 2030, and the proposal to not grant NCT certificates to ICE cars after 2045. For LGVs and HGVs, it was assumed that any increase in annual vehicle-km beyond the 2030 values would be completed using electric vehicles only. The public bus fleet was modelled as being 100% electrified by 2050.

Table 10: Climate Action Plan 2019 Current, 2030 and 2050 Annual CO_2 Emissions

CAP 2019	Current	2030	2050
Annual Emissions (tCO_2)			
Car	1,085,234	501,756	0
LGV	205,014	204,661	0
HGV	247,092	331,732	345,305
Bus	88,953	56,381	0
Rail freight	239	239	0
Passenger rail	37,174	22,294	0
Total	**1,663,707**	**1,117,063**	**345,305**
% change		**-33%**	**-79%**

Table 11: Climate Action Plan 2019 Current, 2030 and 2050 Annual Energy Demand

CAP 2019	Current	2030	2050
Annual Energy (TWh)			
Car	4.023	2.218	0.935
LGV	0.766	0.919	0.591
HGV	0.923	1.337	1.446
Bus	0.337	0.284	0.192
Rail freight	0.001	0.001	0.000
Passenger rail	0.130	0.139	0.151
Total	**6.180**	**4.898**	**3.315**
% change		**-21%**	**-46%**

It can be seen that through these actions, a reduction in emissions of 33% relative to the base year could be achieved by 2030, rising to a 79% reduction in emissions by 2050. This falls well short of the ambition stated in the Climate Action Plan 2019 to reduce transport emissions nationally by 45-50% by 2030. Energy demand is expected to decrease to a lesser degree under these time horizons. It can be seen that the majority of the reductions would be achieved by cars, with a 54% reduction in emissions between 2020 and 2030. A significant proportion of this is due to the 9% projected reduction in total vehicle-km travelled by cars in 2030, based on Codema's linear extrapolation of the NTA's 2028 figures. A serious question remains over the likelihood of such a significant changeover of the car fleet to EVs within the given timeline. As of December 2020, just 5,257 fully electric cars were licensed in Dublin[85], however, according to the Society of the Irish Motor Industry, an additional 4,238 BEVs were registered in Dublin in 2021[86]. While this shows a clearly accelerating trend towards BEV sales, they still only represented 9.7% of all new car registrations in Dublin. Replacing a further 200,000, or 36%, of Dublin's existing car fleet with BEVs by 2030 will require rapid and sustained growth in BEV registrations each year from now up to 2030.

Scenario B - Increased Ambition

Scenario B takes Scenario A as the starting point, and increases the decarbonisation efforts in line with the more ambitious policies announced since the publication of the Climate Action Plan 2019, particularly those contained in the 2020 Programme for Government. This analysis was completed before the publication of the Climate Action and Low Carbon Development (Amendment) Act 2021, the 2021 Climate Action Plan and the Draft Transport Strategy for the Greater Dublin Area 2022-2042, and so any new policies and measures outlined in these recent documents have not

[85] https://www.gov.ie/en/publication/aa05b-irish-bulletin-of-vehicle-and-driver-statistics-2020/
[86] https://stats.beepbeep.ie/

been considered. In this scenario, a target of a 51% reduction in transport carbon emissions was set for 2030, with full decarbonisation by 2050.

The same number of electric cars by 2030 (213,000) has been assumed as in Scenario A, which is already highly ambitious. In order to reach the 51% CO_2 reduction target by 2030, a 23% reduction in distance travelled by the remaining fossil fuel cars would be required, compared to the BaU projection. This would be the equivalent of removing 45,000 fossil fuel cars from Dublin's roads, based on an annual distance driven of 13,337 km per vehicle[87]. Under this potential pathway, it was proposed that 12.5% of this reduction could be achieved through a shift to e-bikes, with the remaining 87.5% evaporating or else shifting to walking, cycling or public transport. For LGVs, a 5% reduction in vehicle-km compared to the BaU scenario has been modelled to reflect improvements in freight logistics planning. Ten percent of the remaining vehicle-km have been shifted to e-cargo bikes, with another 40% delivered by electric vehicles. For HGVs, a 5% reduction in vehicle-km compared to the BaU Scenario is modelled, based on potential efficiencies from improved logistical management systems. The number of electric HGVs would increase significantly from the very low levels proposed in Scenario A, with 20% of the remaining vehicle-km moved by electric vehicles. A further 5% is proposed to be shifted to diesel rail freight, which offers a significant improvement in energy efficiency and GHG emissions over road haulage[88]. For buses, a 25% increase in vehicle-km has been included to provide for the high level of modal shift from cars. An accelerated fleet renewal has also been implemented, with 70% of the Dublin urban fleet fully electric by 2030. Passenger rail service levels remain the same as in Scenario A, although all services are now fully electrified by 2030.

By 2050, the entire transport fleet would consist of zero emission electric vehicles. An ambitious target of a 50% reduction in car vehicle-km was modelled, with half of these kilometres being shifted to e-bikes, and the other half either evaporating or switching to walking, cycling, or public transport. LGV vehicle-km would be reduced by 5% compared to the BaU for 2050, with 25% of the remaining vehicle-km shifted to e-cargo bikes. All other LGV journeys would be carried out using electric vehicles. HGV vehicle-km would be reduced by 5% compared to the BaU situation for 2050. Ten percent of the remaining vehicle-km would shift to electric rail freight, with the other 90% as electrified road freight. A 50% increase in bus vehicle-km is modelled, in anticipation of a strong policy shift away from private cars. All bus travel will be fully electrified by 2035. Passenger rail services will increase in line with the rail projects planned under the 2016-2035 Greater Dublin Area Transport Strategy.

It has been assumed in this analysis that electric road transport refers to battery electric vehicles. Direct electrification via overhead catenary lines may be considered as an alternative for HGVs on major freight routes, and would have to be considered as part of an overall national strategy. Hydrogen fuel cell vehicles may have some role to play in decarbonising heavy transport; however, it is expected that for HGVs, battery electric or direct overhead/on-road electric systems will be able to provide the required vehicle range at a lower cost[89].

Table 12: Increased Ambition Current, 2030 and 2050 Annual CO2 Emissions

Increased Ambition	Current	2030	2050
	Annual Emissions (tCO_2)		
Car	1,085,234	301,054	0
LGV	205,014	154,575	0
HGV	247,092	262,760	0
Bus	88,953	70,476	0
E-bike, e-cargobike	0	789	0
Rail freight	239	11,324	0
Passenger rail	37,174	13,446	0
Total	**1,663,707**	**814,423**	**0**
% change		-51%	-100%

[87] Average annual distance driven by cars in Dublin, CSO Transport Omnibus 2019

[88] https://www.irishrail.ie/Admin/getmedia/685e9919-f012-4018-879b-06618bb536af/IE_Rail-Freight-2040-Strategy_Public_Final_20210715.pdf

[89] https://www.transportenvironment.org/discover/how-decarbonise-long-haul-trucking-germany/

Table 13: Increased Ambition Current, 2030 and 2050 Annual Energy Demand

Increased Ambition	Current	2030	2050
	Annual Energy (TWh)		
Car	4.023	1.331	0.468
LGV	0.766	0.758	0.421
HGV	0.923	1.193	0.641
Bus	0.337	0.307	0.288
E-bike, e-cargobike	0.000	0.007	0.031
Rail freight	0.001	0.012	0.009
Passenger rail	0.130	0.114	0.151
Total	6.180	3.722	2.009
% change		-40%	-67%

Challenges & Barriers

The Business-as-Usual projections outlined assume that levels of car usage per capita will remain constant from 2030 to 2050. In order to achieve a 51% reduction in GHG emissions by 2030 and net zero by 2050, this level of car dependency will need to be reduced significantly and quickly. The Government's latest Climate Action Plan 2021 includes a target of reducing fossil fuel vehicle-kilometres by 10% nationally, which pales in comparison to the minimum 23% reduction of fossil fuel vehicle-km required to achieve a 51% decrease described here. In order to meet the target of 213,000 BEVs by 2030, BEV sales would need to increase by roughly 33% year-on-year to the end of this decade. Currently, around 45,000 new cars are sold per year in Dublin. In parallel with this, overall car sales will need to reduce. This will be a big challenge, particularly as the motor sales lobby in Ireland is targeting a 28% increase in car sales nationally in 2022 compared to the relatively high pre-covid sales figures of 2019.[90] At present, many drivers are reluctant to switch to BEVs as vehicles which suit their specific needs are not yet available on the market, or long waiting lists exist. Considering that cars will typically be driven for 15 years, any new ICE purchase will be locking-in fossil fuel consumption until the mid-2030s. Until sufficient BEV models are available to meet consumer demands, drivers must therefore be encouraged to hold on to their existing fossil-fuelled cars for longer and to wait until a suitable BEV is available to them before purchasing a new vehicle.

Spatial constraints

One of the biggest challenges with enabling sustainable transport is providing the space for it, particularly in urban areas. In urban Dublin, there is very limited scope for widening of existing roadways to allow for new bus lanes, cycle lanes or widened footpaths. The BusConnects project has faced this difficulty, and rather than reducing the priority and space allocated to private motor vehicles, has instead opted to widen many existing roads, including through the use of compulsory purchase orders. This approach has been opposed by many local communities who feel that their urban villages are being turned into highways. This is a very important point in the discussion around urban transportation and the public realm. Wide roads can severely impact upon the social fabric of an area and sever communities. A reallocation of the existing road space in Dublin should therefore be considered first, in a manner which prioritises the most sustainable and equitable means of transportation but also reinvigorates communities. This must take into account local needs and not just those of commuters passing through. The integration with nature-based climate solutions, trees, benches and other social amenities must be considered as part of any major redesign.

Accessibility to transport

Opponents to the redistribution of road space away from cars and towards more sustainable modes will often point out that "not everyone can cycle". While this is true, it is equally that not everyone can drive, nor should be forced to drive. Firstly from a cost perspective, the AA estimates that the average cost of running a family car in Ireland is in the region of €10,700 per year, making forced car ownership a significant strain on many household budgets.[91] Out of a

[90] https://www.independent.ie/life/motoring/car-news/demand-may-exceed-supply-as-new-ev-sales-to-reach-15000-next-year-41172188.html
[91] https://www.theaa.ie/aa/motoring-advice/cost-of-motoring.aspx

total population of 5.01 million people in Ireland[92], there are currently 3.09 million driving licences held.[93] This means that over 38% of the population cannot drive. This includes many children, teenagers, older people and people with disabilities. Many parents drive their children to school and other activities as they feel the roads are too dangerous for walking or cycling on. This is clearly evidenced by the number of girls cycling to school nationally, which has plummeted from 19,000 in 1986 to just 700 in the 2016 Census (although other social barriers are also factors here).[94] 'Companion' journeys, such as school run trips, made up 20% of all trips in the country in 2019, while for females this figure rose to 25% of all trips[95]. By encouraging active travel and public transport use from a young age, lifelong habits can be formed. If safe, comfortable and convenient infrastructure and services were available, a huge proportion of car trips could be eliminated, while also providing much needed independence to younger people. In addition to better infrastructure, the rollout of default 30 km/h speed limits in built up areas, as required by the UN Stockholm Declaration of 2020 of which Ireland is a signatory, would assist greatly in making active travel safer. According to the Road Safety Authority, if a person driving a car hits a pedestrian at 50 km/h, there is a 50% chance that the pedestrian will be killed. Cutting the car's speed to 30 km/h reduces the probability of the driver killing the pedestrian to just 10%.[96]

Similarly, a significant number of older people or people with disabilities are unable to drive for a variety of reasons, so alternative mobility options must be catered for. Facilities to enable safe walking and usage of e-bikes, trikes, mobility aids and public transport need to be considered first. Improving public transport and active travel options for those who can avail of them will mean less traffic for those people who are truly reliant on cars to get around. Where the use of cars is unavoidable, then priority should first and foremost be for those who genuinely need to travel by car. Accordingly, car parking, where provided, can be heavily weighted towards 'blue badge' or 'age friendly' spaces. Significant accessibility issues currently exist in Dublin, such as narrow footpaths blocked by 'street clutter', unreliable lifts at rail stations and the requirement for wheelchair users to provide 24-hour notice prior to embarking on certain public transport services.

The areas of interaction between pedestrians and cyclists is another concern, particularly where current designs dictate that cyclists must transition from segregated tracks into 'shared space' with pedestrians at junctions or at bus stops. This conflict can be engineered out to a great extent through well-designed segregation at junctions and bus stop bypasses. Ireland is not the first country to encounter this issue, and should look to countries such as the Netherlands, who have been refining designs that deal with these conflicts for over 50 years, for guidance. Recent designs from local authorities in Dublin have shown that the NTA is willing to engage in a constructive manner to go beyond the designs set out in the National Cycle Manual and fund safer Dutch-style cycling infrastructure.

The tendency for women to carry out more complex trips than men, known as 'trip chaining', similarly needs to be considered in the design of public transport and active travel networks. The recently launched 90-minute fare for public transport in Dublin should assist greatly in reducing the cost of trip chaining. Women are also more likely to travel encumbered, that is, with a child or a heavy or cumbersome object such as a pram.[97] These particular needs must be addressed in the design of transport systems, and not just the typical commuting journeys into the city centre.

'Electrified' vehicles

Reducing the number of trips taken by car will be a big challenge, however, the decarbonisation of the remaining vehicle stock will be just as difficult a task. In both Scenarios A and B, it was assumed that electric referred to fully electric vehicles (regardless of whether battery electric, hydrogen fuel cell, or powered via overhead catenary lines or electric roads), and excluded PHEVs. This is due to emerging evidence that in real-life usage, there is a significant gap between the official type-approval test figures and actual emissions for PHEVs. Actual emissions from fossil fuel usage have been estimated to be 2-4 times higher than those achieved in Worldwide Harmonised Light Vehicle Test Procedure (WLTP) test cycles, the new global standard for determining fuel economy and emissions for cars. This is due largely to the

[92] https://www.cso.ie/en/releasesandpublications/ep/p-pme/populationandmigrationestimatesapril2021/mainresults/
[93] https://www.cso.ie/en/releasesandpublications/ep/p-tranom/transportomnibus2020/driverandvehicletesting/
[94] https://www.rte.ie/news/2022/0126/1276020-girls-cycling-to-school-ireland/
[95] https://www.cso.ie/en/releasesandpublications/ep/p-nts/nationaltravelsurvey2019/whywetravelled/
[96] https://www.rsa.ie/road-safety/campaigns/anti-speeding
[97] https://www.tii.ie/technical-services/research/TII-Travelling-in-a-Womans-Shoes-Report_Issue.pdf

reality that PHEVs are not charged as often as assumed in the test procedure.[98] The average range of new BEVs launched in Europe in 2020 was 380 km, with public rapid charge points in Ireland now able to supply 100 km of charge in as little as six minutes.[99] As such, PHEVs as a transitional technology are essentially obsolete.

The emergence of 'disruptive' BEV manufacturers, primarily Tesla, with battery ranges of 400+ km, has led to a significant increase in demand for fully electric vehicles over the past number of years, beyond what many of the established car brands had envisioned. A lack of ambition and poor market analysis by many of these large global manufacturers, combined with recent Covid-19 related supply chain issues, has led to a shortage of BEVs in many markets, including Ireland. In order to keep overall car sales figures up, certain manufacturers' marketing campaigns have been misleadingly directing customers towards 'electrified' fossil fuel vehicles, in the form of mild hybrids and plug-in hybrids. Incredibly, the manufacturer which sold the greatest number of cars in Ireland in 2021 did not even offer a single BEV model. This is having a hugely detrimental effect on current efforts to decarbonise transport, locking in high levels of fossil fuel consumption and carbon emissions for at least another decade.

In addition to this, current EU targets have not been able to keep up with the increase in demand for EVs. The existing EU targets are now not ambitious enough to enable the scale of decarbonisation that is required by 2030 and 2050. Recent research suggests that if car manufacturers in Europe follow their own voluntary EV plans, CO_2 emissions from new cars could be reduced by 25-35% by 2025.[100] However, the mandatory EU targets only require a 15% reduction over this period. This situation may lead to manufacturers backsliding on their EV targets, forcing more consumers into the purchase of fossil fuel vehicles and locking in additional CO_2 emissions. Loopholes in the EU targets are also being manipulated by manufacturers, particularly the mass adjustment factor which allows for increased CO_2 emissions limits for heavier vehicles, and the 'super-credits' attributed to vehicles with tailpipe emissions of less than 50 gCO2/km, which treat PHEVs the same as BEVs.[101] By selling larger and heavier PHEVs, manufacturers are able to take advantage of this system and reduce their overall fleet decarbonisation targets. The EU is, however, aware of the performance gap between type-approval and real-world emissions, and has set out regulations to ensure that all new cars and vans sold from 2021 on will have their actual energy and emissions data collected and reported through onboard fuel consumption monitoring systems.

It could very reasonably be argued that the Government's EV targets should be broadened to include e-bikes and e-cargo bikes, given the transformative role they can play in urban, suburban and even rural settings.

The growth of SUVs

Due to their size and weight, sports utility vehicles (SUVs) consume 10-30% more energy per kilometre travelled, compared to a standard car. The International Energy Agency estimates that globally in 2020, the reduction in oil consumption from the increased market share of EVs was completely cancelled out by the growth in SUV sales over the same period.[102] The same analysis found that at a European Union level, SUVs were the leading contributor to overall CO_2 emissions growth in the decade from 2010 to 2020. In Ireland, the average emissions per-kilometre for new cars has not fallen since 2015[103]. Any progress that was being made in lowering the emissions of new cars has been nullified by the rapid growth in sales of SUVs. In 2021, almost 53% of all new car registrations in Ireland fell into the "Jeep/SUV" market segment.[104] In Dublin, this figure was slightly lower at just under 48%, compared to just 11% of sales a decade earlier. Manufacturers are able to market SUVs as premium products, and therefore can achieve a higher profit margin per vehicle. Despite the larger exterior dimensions of SUVs, this often does not translate to additional interior space. In addition to occupying more street space, SUVs are also heavier than traditional cars, resulting in increased particulate emissions from road wear, brake dust and tyre wear. The elevated bonnets reduce visibility of other road users and, in the event of an impact with a pedestrian, are more likely to cause death as the person's abdomen and organs will be struck first, rather than their lower limbs. It is also more likely that a pedestrian will be dragged underneath the vehicle

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98 https://theicct.org/publication/pathways-to-decarbonization-the-european-passenger-car-market-2021-2035/
99 https://www.esb.ie/ecars/news/2021/2021/07/07/esb-unveils-first-high-power-ev-eight-bay-charging-hub
100 https://www.transportenvironment.org/discover/electric-vehicle-boom-set-to-stall-as-lost-decade-looms/
101 https://ec.europa.eu/clima/eu-action/transport-emissions/road-transport-reducing-co2-emissions-vehicles/co2-emission-performance-standards-cars-and-vans_en
102 https://www.iea.org/commentaries/carbon-emissions-fell-across-all-sectors-in-2020-except-for-one-suvs?
103 https://www.rte.ie/brainstorm/2022/0201/1277072-suvs-ireland-fuel-safety-energy-climate-change/
104 https://stats.beepbeep.ie/

than flipped over the bonnet.[105] In order to tackle the sales of these fuel-hungry vehicles, a vehicle registration tax scale based on vehicle weight could be implemented to disincentive the purchase of such vehicles. Such a system has recently been introduced in France, and applies to vehicles weighing over 1,800 kg. A more coordinated approach also needs to be taken at EU policy level, forcing manufacturers away from the development of these inefficient vehicles. Unfortunately for now, consumers have very little alternative choice, with these models being forced on them by manufacturers. This is a particular issue for families with three or more children, as the range of new non-SUV family cars capable of accommodating three child seats is extremely limited.

EV charging

Due to the significant advances in battery technology, with the average new EV now able to cover almost 400 km on a single charge, range anxiety is no longer considered a significant barrier to EV adoption for most trips in Ireland. This has been replaced, however, by charger anxiety, with the fear that a public charge point will be out of order, already in use, or the space occupied by a fossil fuelled car on arrival. This is a significant concern for EV drivers who do not have their own private off-street parking. A significant proportion of car owners in Dublin do not have access to off-street parking and will require public charging infrastructure if they are to switch to BEVs. Many people living in apartment buildings or housing estates with designated car parking may also encounter significant obstacles to installing EV charging. Further barriers also exist around ownership and landlord permissions for those in rented accommodation. An estimate of the current proportion of cars without off-street parking in Dublin was produced as part of the Dublin Local Authority EV Charging Strategy in 2020. Estimates at a local authority level are provided in the table below, while the map on the next page provides a more detailed analysis at an electoral district level. This is not a precise breakdown, but it does allow for a relative comparison between different areas and provides an indication of the areas where this issue may be most pronounced. As might be expected, the city centre areas appear to have the highest proportion of on-street parking, with far higher levels of off-street parking available in the less dense suburbs and rural areas.

Table 14: Estimated proportion of cars parked off-street versus on-street in each of the Dublin Local Authority areas

	DCC	DLR	FCC	SDCC
Private off-street	56%	72%	77%	78%
Shared off-street	14%	13%	11%	8%
On-street	29%	15%	12%	14%

[105] http://www.tara.tcd.ie/bitstream/handle/2262/41169/Pedestrian%20risk%20from%20cars.pdf

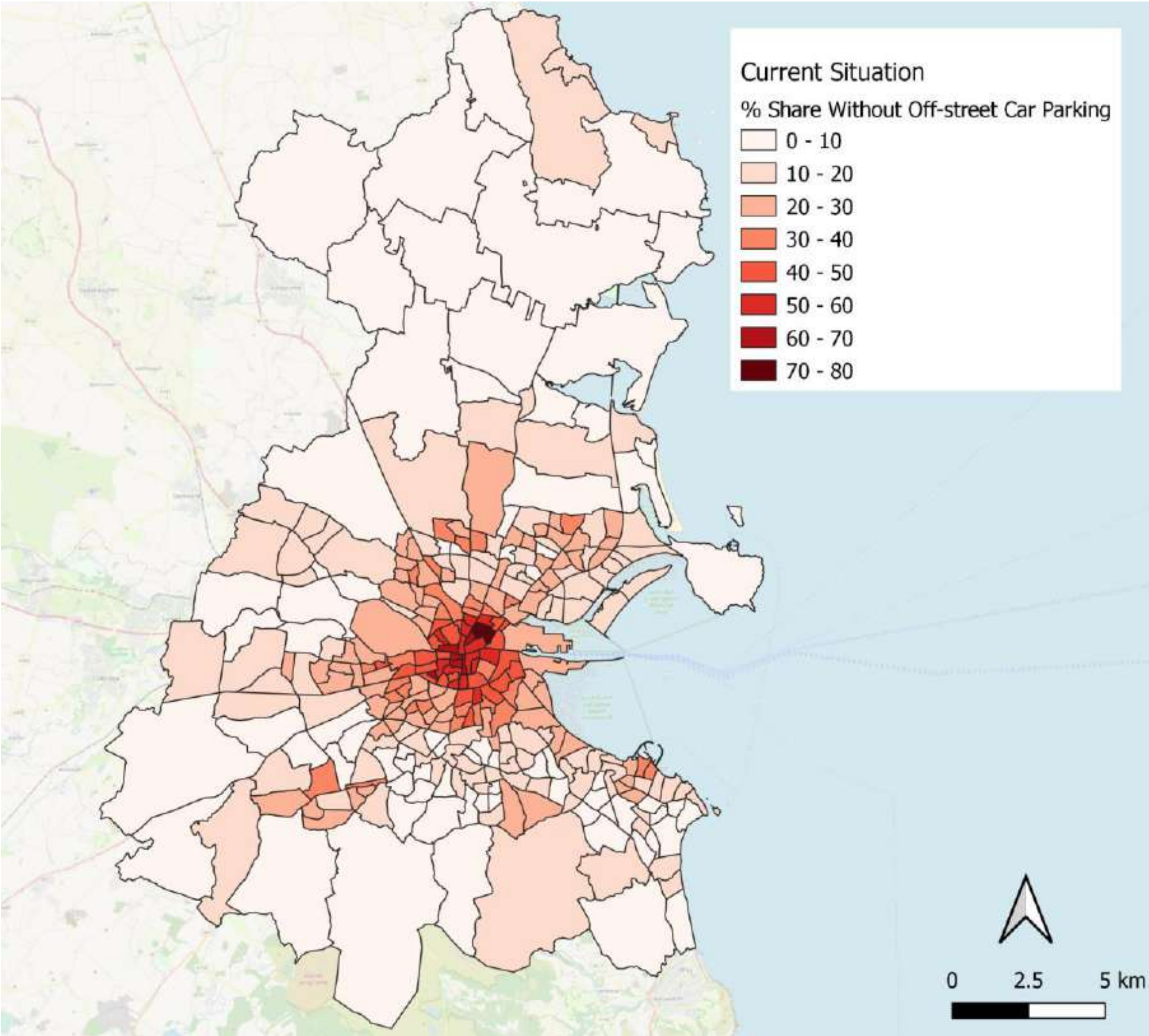

Figure 58: Estimated share of cars without off-street parking (Source: Dublin Local Authority EV Charging Strategy, December 2020)

In areas with limited off-street parking, innovative solutions may be required. Trailing charging cables across public footpaths to cars parked on the street could lead to Public Liability issues as it creates a trip hazard, and could be particularly dangerous for the elderly or visually impaired. In addition to this, extending cables outside the equipotential zone of the house may pose an additional hazard in the case of damage to the cable, with an increased risk of electric shock if a broken neutral occurs.[106] The placement of EV charging pedestals on footpaths outside every home would instil further car dominance over pedestrians and completely ignores the overall strategy of promoting active travel and public transport over private car convenience. Instead, high-speed EV charging infrastructure could be installed in groups or 'hubs', using existing road space. The Dublin Local Authority EV Charging Strategy estimates that approximately 500 rapid (50-150 kW) residential public charge points in hubs such as these will be required to serve a projected demand of 138,000 BEVs in Dublin by 2030, with 34,000 of these solely reliant on public charging. An additional 2,500 en-route and destination charge points are also expected to be needed to cater for this projected demand. In a scenario with 213,000 BEVs by 2030, this may necessitate over 4,600 rapid charge points in total.

One aspect of EV charging which needs serious further consideration is the fairness of the EV transition. It is typically the wealthier car owners who will be able to afford larger homes with private off-street parking. These car owners will be able to avail of cheap night time electricity rates to charge their vehicles, while the less well-off will be forced to pay higher rates to charge their vehicles at high-speed public charge points. This difference is running costs could easily run

[106] https://www.lgma.ie/en/publications/general-publications/local-authority-electrification-of-fleet-and-ev-charging-guidance.pdf

to several hundreds of euro per year, although overall all EV drivers should still be saving money when compared to the running costs of fossil fuel vehicles.

The need for residential EV charging should be considered in conjunction with the need identified in this analysis to rebalance the use of public space away from private cars. The storage of private cars on public streets is not an efficient use of the public realm, with cars typically left parked and unused for over 90% of the time. Footpath parking is also a serious issue in many of the areas identified with high levels of on-street parking, with a growing culture of non-compliance and a lack of enforcement over the past number of decades as the number of cars in the capital rapidly grew. Providing better active travel and public transport links should be prioritised in these areas over the provision of public EV charge points outside every home. Obviously these modes cannot completely replace car travel, so alternative options should also be maintained. Much of Dublin's urban footprint is ideal for car-sharing schemes, with two separate operators currently active in the county. This more efficient use of shared vehicles should be encouraged, rather than individual car ownership. Studies have shown that a single shared vehicle in an urban location can take up to 15 privately owned vehicles off the road.[107] However, a recent study carried out in Dublin found a lower rate of 'car shedding' currently happening here.[108] Measures proposed in the Five Cities Demand Management Study, such as congestion charging, increased parking fees and a reduction in the number of on-street car parking spaces, would likely lead to an increase in this rate.

Buses and freight vehicles

The decarbonisation of HGVs is seen as one of the most difficult areas to tackle. In the Government's Climate Action Plan 2019, the lack of availability of suitable electric HGVs was cited as a significant barrier to decarbonisation of this sector. Compressed natural gas (CNG) had been seen by some, including the EU's Connecting Europe Facility and Gas Networks Ireland, as a potential low-carbon alternative to diesel for heavy freight. This was based on the premise that fossil gas would be supplemented by renewable gas injected into the gas grid, ensuring a lower carbon fuel supply. Progress in rolling out a network of public refuelling stations has been very slow to develop, with just seven such stations currently in operation in Ireland. More significant, however, is the reality that at present, 99.9% of the gas in the grid is fossil fuel, with the injection of biomethane making up just 0.1% of the total.[109] The Government has set a target of 1.6 TWh of renewable gas in the grid by 2030 in the CAP 2021, representing 2.9% of total gas demand. This is well below the 20% renewable content proposed to be included in road diesel by that date.

Much research has recently been carried out into the energy efficiency and environmental benefits of CNG as a transport fuel. The Government carried out a public consultation on a Review of Sustainable Mobility Policy in late 2019. The Background Paper 5 entitled 'Greener Buses - Alternative fuel options for the urban bus fleet' found that "CNG does not provide benefits to transport's carbon emissions profile in the short term". It also suggested that blending CNG with biomethane may present potential for decarbonisation of the urban bus fleet, but that the Irish market would not be able to meet demand, and higher-cost biomethane would need to be imported from the EU.[110] The Department's 'Report on Diesel-and Alternative-Fuel Bus Trials', published in December 2019, compared operational data from diesel, diesel-hybrid, CNG and battery electric buses on urban routes in Dublin and Cork. This research trial found that battery electric buses are the most energy efficient and emit the lowest amount of local NOx, and that CNG buses are less efficient than diesel buses. It also found that NOx emissions from CNG buses were roughly on a par with those from diesel buses.[111] From a life cycle GHG emissions perspective, the study found that hybrid buses fuelled by 100% biodiesel could provide the greatest reduction in emissions, if sufficient hydrotreated vegetable oil (HVO) fuel was available. This would also be the most expensive option of all those considered, mostly due to fuel costs. In order for battery electric buses to provide the same reductions in GHG emissions, the carbon intensity of the electricity grid would need to reduce by 80% from 2019 levels to roughly 94 gCO2/kWh. Based on the projections used throughout this report, this is expected to be achieved by the early 2030s. Aside from potential difficulties in sourcing enough HVO fuel, the EU's Clean Vehicles Directive would also significantly restrict the number of vehicles which could

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107 https://www.researchgate.net/publication/46440175_Carsharing's_Impact_On_Household_Vehicle_Holdings_Results_From_A_North_American_Shared-Use_Vehicle_Survey

108 https://www.sciencedirect.com/science/article/pii/S2213624X20301589

109 https://www.seai.ie/blog/its-not-working/index.xml

110 https://www.gov.ie/en/consultation/f1b503-public-consultation-on-a-review-of-sustainable-mobility-policy/

111 https://www.gov.ie/en/publication/7251e2-low-emission-bus-trials-report/

be run on biodiesel, as 50% of new 'clean' vehicles must be 'zero-emission' battery electric or hydrogen fuel cell electric vehicles (FCEVs). FCEV buses were not included in the 2019 trial as suitable vehicles were not available at the time.

For buses and road freight, battery electric vehicles are likely to be the dominant technology in the decarbonisation of this sector. In 2023, over 60 battery electric trucks are due to be on sale in the European market, with vehicles with a range of up to 500 km coming onstream in 2024. It is now widely believed that the total cost of ownership (TCO) for battery electric trucks will reach parity with diesel trucks as early as the mid-2020s, if the right policy measures and incentives are put in place.[112] FCEVs are seen as the main alternative technology for decarbonising the heavy transport sector, however they are not expected to enter series production until the latter part of this decade. Hydrogen fuel cell vehicles are relatively inefficient, with a typical overall 'well-to-wheel' efficiency of 33%, versus 75% for battery electric drivetrains.[113] For heavy road transport, it is seen as unlikely that FCEVs will ever be cheaper to run than BEVs due to their higher fuel costs.[114] Hydrogen fuel should therefore instead be reserved for hard-to-abate sectors, as described in detail in the Green Hydrogen section of Appendix C. From a transport perspective, hydrogen may be most suitable for shipping and long-haul aviation.

Under EU legislation, drivers must take mandatory breaks of 45 minutes every 4.5 hours. In Europe, 80% of truck activity is carried out over distances of less than 800 km. In Ireland, trips are much shorter than in mainland Europe, with just 6% of road freight journeys longer than 500 km in distance.[115] With the development of megawatt scale EV charging infrastructure, up to 400 km of range could be added within this 45-minute break.

Rail freight is almost non-existent in Ireland, in sharp contrast with most other European countries. Rail freight was not specifically addressed in CAP 2019, although the publication of an updated strategic rail review paper was included as an action. In July 2021, Irish Rail published details of their Rail Freight Strategy 2040. This strategy aims to significantly increase the share of freight transported via rail in Ireland in line with other European countries, with a five-fold increase in rail freight volumes by 2040. This will include the creation of rail freight terminals at various strategic locations in the country, including at each Tier 1 sea port and a major strategic freight terminal to the west of Dublin. The document states that rail freight is typically cheaper than road transport for journeys in excess of 150 km, while GHG emissions from rail freight are 76% lower per tonne-kilometre compared to those from road freight.[116] In addition to this, the All Island Strategic Rail Review public consultation was jointly launched by the Irish and Northern Irish Governments in November 2021. While this review is focused mainly on passenger transportation, rail freight is also covered within the scope of the analysis.

For urban and suburban deliveries, e-cargo bikes offer significant emissions savings potential and efficiencies over vans, particularly in congested areas. One recent Austrian study found that up to 51% of urban freight journeys could be replaced by e-cargo bikes.[117] The Dublin Local Authorities have been leading the way nationally in promoting the use of e-cargo bikes for business, with pilot schemes implemented in Dún Laoghaire-Rathdown, Fingal and Dublin City over the past year where businesses could trial an e-cargo bike for a number of months at discounted rates.

Costs

Subsidies and grants

In recent years, new BEVs and PHEVs purchased in Ireland were subsidised by up to €10,000, through a grant of up to €5,000 from SEAI and VRT relief of up to €5,000. Government EV targets still include PHEVs, although the focus is now more on BEVs, with VRT relief for hybrid vehicles discontinued in 2021, and grants for PHEVs discontinued in January 2022. Up to the end of 2023 at least, BEVs and electric motorcycles can still benefit from VRT relief up to a maximum

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112 https://www.transportenvironment.org/wp-content/uploads/2022/02/2022_02_battery_electric_trucks_HDV_factsheet.pdf
113 https://www.transportenvironment.org/discover/electrofuels-yes-we-can-if-were-efficient/
114 https://www.transportenvironment.org/discover/how-decarbonise-long-haul-trucking-germany/
115 https://www.cso.ie/en/releasesandpublications/ep/p-rfts/roadfreighttransportsurvey2017/
116 https://www.irishrail.ie/Admin/getmedia/685e9919-f012-4018-879b-06618bb536af/IE_Rail-Freight-2040-Strategy_Public_Final_20210715.pdf
117 https://www.sciencedirect.com/science/article/pii/S2352146516000478

of €5,000. This relief reduces in value on a sliding scale for vehicles with an open market selling price above €40,000, with no VRT relief available for selling prices above €50,000. BEVs are also eligible for a benefit-in-kind tax rate of 0%.

The purchase price of BEVs in Ireland is still approximately €5,000 more than that of equivalent fossil fuel vehicles, even after Government subsidies. However, leading industry analysts expect price parity (without any Government subsidies) between BEV and ICE cars in the second half of this decade. The total cost of ownership, taking into account purchase price, fuel, maintenance and tyres, is already lower for many BEVs compared to ICE cars. This is expected to be the case across the board and without government subsidies by 2025, with purchase price parity to follow within a year or two of this, depending on the market segment.[118]

The second-hand EV market in Ireland is still very small, with any available models commanding a relatively high price. This is likely to remain this way over the next number of years as supply remains quite limited and demand continues to rapidly grow. Imports of second-hand EVs are limited by the right-hand drive requirements in Ireland compared to continental Europe, with Brexit making imports from the UK a much more tricky and expensive option than what previously had been the case. Grants towards the purchase of second-hand electric vehicles have been implemented in a small number of jurisdictions, including France, but are not currently planned to be made available in Ireland.

At present, the only national level support currently available for bikes or e-bikes is the Cycle-to-Work tax saver scheme. This tax break is only available to PAYE employees (whose employers must first agree to administer the scheme), and is inherently unfair by providing higher subsidies to higher earners. Crucially, this scheme also excludes many groups within society who need the most support - students, retirees and those in short-term employment or working in the 'gig' economy. Additionally, the scheme may only be availed of once every four years, even if a bicycle is stolen or damaged and needs to be replaced. This compares very poorly with the grant system and VRT relief provided for EVs, which are freely available to any member of the public, as often as they like. Far more generous and universally accessible supports and subsidies are available across Europe and further afield. For example, in England businesses can receive grants of up to £4,500 for 3-wheeled e-cargo bikes, while France has a scrappage scheme for older cars, which provides up to €1,500 in credit towards the purchase of an e-bike.[119] Another French scheme provided a subsidy of €50 for citizens to get repairs carried out to their existing bikes, in a bid to get people out cycling on them again. This has been a highly successful scheme, with the voucher availed of by over one million citizens.[120] Reducing the VAT rate to 0% on bikes and e-bikes is another approach which may have a significant impact on the uptake of active travel.

For public transport users, the Taxsaver Commuter Ticket scheme allows those paying PAYE to avail of cheaper annual public transport tickets. As with the Cycle-to-Work scheme, however, this provides greater subsidies to higher earners and is not accessible to all. A new scheme is currently being progressed by the NTA, which would allow more flexible tickets to accommodate workers who are now working remotely part of the time, however it is unclear when this will be made available[121]. In their 2022 Budget, the Government announced a 50% reduction in public transport fares for young people up to the age of 23, while the Free Travel Pass remains in place for those over 66 or in receipt of Disability Allowance, Blind Pension, Carers Allowance or Invalidity Pension. A further 20% reduction in public transport fares was announced in February 2022 in response to the rising cost of fuel and to incentivise people to shift to public transport. This is currently planned to be in place until the end of 2022.

Infrastructure Costs

The table on the next page presents the typical construction costs of various transport options, using actual or budgeted project costs in a Dublin-specific context where available. Rail projects are by far the most expensive option, on a per-kilometre basis. The proposed DART+ tunnel project, for example, would require hugely expensive tunnelling through Dublin's historic core, running from Heuston to Pearse Station. Overground rail projects can also be very expensive in Dublin, with estimates for the Luas extension to Finglas coming in at €250 million per kilometre of track. In contrast to

[118] https://theicct.org/publication/pathways-to-decarbonization-the-european-passenger-car-market-2021-2035/, https://www.transportenvironment.org/discover/evs-will-be-cheaper-than-petrol-cars-in-all-segments-by-2027-bnef-analysis-finds/

[119] https://irishcycle.com/2021/11/08/around-the-world-cargo-bicycle-and-electric-bicycle-grants/

[120] https://www.thelocal.fr/20200914/france-pledges-20-mn-euro-to-expand-bike-repair-bonus/

[121] https://www.irishtimes.com/news/ireland/irish-news/flexi-tax-saver-tickets-still-work-in-progress-says-irish-rail-1.4805290

this, the cost of new dedicated bus lanes under the BusConnects programme is projected to come in at approximately €10 million per kilometre, and will also include up to 200 km of cycle infrastructure (although the quality of this cycle infrastructure appears to be sub-standard in many instances). This lower cost is achieved through the reallocation of existing road space away from private motor vehicles, although the widening of roadways to maintain the status quo has still been proposed in many places.

Electrification of existing railway lines or roads is relatively cheap from an infrastructure perspective. For a twin-track railway, this is estimated at approximately €3.5 million per kilometre, while electrifying roads with overhead catenary lines is slightly cheaper at €3.1 million per kilometre. Fleets will also need to be changed in order to make use of these electrified roads and railways. Innovative hybrid solutions, where battery packs and electric overhead lines are combined, may provide a flexible approach to electric transport. This model is due to be implemented shortly by Iarnród Éireann, with an order of 65 battery electric multiple unit (BEMU) carriages recently placed. These carriages will operate on the extended DART routes, and will have the ability to travel up to 80 km on battery power alone, while being powered by overhead lines in other areas of track where this is available.

Table 15: Cost estimates for typical transport infrastructure projects

	Cost per km (million €)
DART+ Tunnel	789
New Luas lines	250
Metrolink	158
Typical new road	60
BusConnects	10
DART+ electrification	3.5
Road electrification	3.1
High quality cycle track	1.6
Greenfield cycle track	0.05
Signalised pedestrian crossing (per crossing)	0.01

The cost associated with the provision of high-quality cycling and walking infrastructure can vary greatly, depending on the location and interactions with other infrastructure. A simple greenway project can come in at about €50,000 per kilometre, while a high-quality urban greenway will typically cost closer to €1.6 million per km. The requirement to include over- or underpasses at intersections with major roads, railways or waterways can add greatly to this cost, but is often the preferred option as priority is maintained for active travel users while providing time savings and removing potential conflict with other road users. Providing multiple signalised pedestrian or cycle crossings is not a cheap alternative to this, with a typical cost of up to €100,000 per crossing.

Fleet replacement costs

The additional upfront costs associated with electrification of existing road vehicles in Ireland are presented in Table 16 below. These are typical figures sourced from industry and public sector analysis, and are exclusive of any Government subsidies. The figures are presented on a per-vehicle basis, and are relative to a standard diesel counterfactual. For cars, it is expected that price parity with fossil fuel vehicles will occur around 2027. This point is expected to be reached by LGVs even sooner, possibly by 2025. The additional costs for battery electric HGVs and buses are particularly high at present, however they are expected to reach price parity with diesel vehicles by the end of this decade. For battery electrification of the rail fleet, BEMUs are also included below. The cost per carriage is approximately 50% higher than standard overhead electric multiple units (EMUs) as used on DART services; however, this differential is expected to narrow over the coming decade as battery costs continue to decline.

Table 16: Battery electric vehicle additional costs per vehicle

Battery Electric Vehicle	Additional Cost (€)
Car	15,000
LGV	26,300
HGV	317,000
Bus	200,000
BEMU	1,600,000

EV Charging infrastructure

The cost of EV charging infrastructure can vary widely depending on the capacity and geographical location. Basic 3-7 kW home chargers can typically be installed for less than €1,000. The SEAI currently offers a grant of €600 towards this cost. A public fast charging pillar, with two charge points of 22 kW capacity each, can typically cost in the region of €16,500 to install. Going beyond this range, costs can vary significantly due to local electricity network constraints, however for a typical rapid (43-50 kW) or ultra-rapid (100-350 kW) charge point, a minimum cost of €75,000 might be expected. Although none have yet been installed in Ireland, megawatt charging system (MCS) chargers with capacities of up to 1.2 MW lie at the upper end of the scale. These may cost in the region of €0.5 million, based on research conducted in Germany.[122]

Table 17: Typical EV charge point installation costs

EV Charge Point	Installation Cost (€)
Domestic (3-7 kW)	1,000
Fast x2 (22 kW)	16,500
Rapid (43-50 kW)	75,000+
Ultra-Rapid (100-350 kW)	75,000+
MCS (1.2 MW)	464,000

[122] https://www.transportenvironment.org/discover/how-decarbonise-long-haul-trucking-germany/

Pathway

Meeting our Emissions Targets

Throughout this report, Codema has recommended ways to reduce emissions in the county. If the Dublin Region were to carry out all the suggested recommendations, it could potentially reduce emissions by a total of 4,103 ktCO_2 per year by 2030 and 8,240 ktCO_2 per year by 2050, through the uptake of low-carbon technologies and increased renewable energy generation. Furthermore, it can potentially increase renewable energy by 2050 in the Dublin Region by 14,776 GWh. This decarbonisation pathway will help the region to meet its 2030 targets and exceed its 2050 target, where renewable electricity generation exceeds demand making the Dublin region a net exporter of renewable electricity which results in the region achieving negative emissions (-295 ktCO_2).

The figure below shows the gap-to-target (i.e. difference between the projected business-as-usual emissions and the target emission levels) which is represented by the dotted lines. It also outlines the technology adoption levels required to meet these targets.

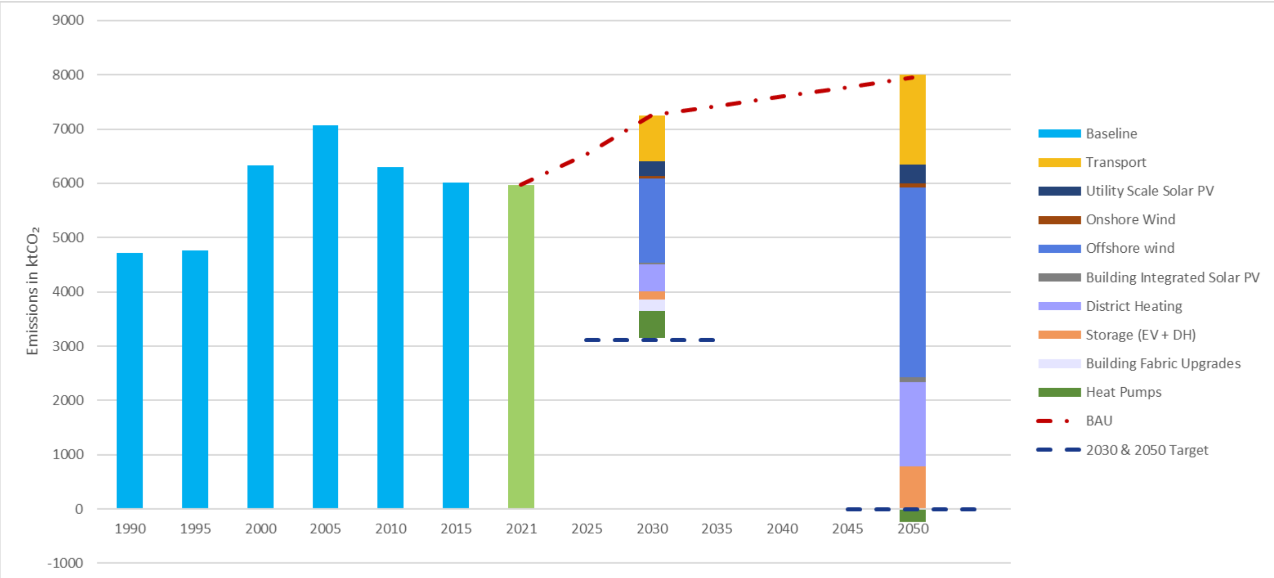

Figure 59: 2030 and 2050 low-carbon and net-zero pathways

The pathways to meeting our 2030 and 2050 targets depend on the increase in renewable energy generation. This increase in renewable energy can help the region to make use of indigenous energy sources to reduce its reliance on fossil fuel imports, and emissions. The renewable electricity generation potential for 2030 and 2050 are set out in the table below. As can be seen, it is clear that offshore wind energy represents the biggest decarbonisation opportunity for Dublin, it can help the region reduce its emissions by 21% in 2030 and 44% in 2050 (from projected business-as-usual scenario)

Table 18: Carbon Savings from Renewable Electricity Generation Technologies in Dublin

Technology	GWh		tCO_2 Saved	
	2030	2050	2030	2050
Utility-Scale Solar PV	854	1,057	277,124	343,036
Onshore Wind	130	325	42,163	105,572
Offshore Wind	5,241	13,124	1,700,768	4,258,600
Building-Integrated Solar PV	84	270	27,237	87,763
Curtailment Assumed Avoided by EV+DH	462	2,421	149,892	785,551
Total	**6,309**	**14,776**	**2,047,292**	**4,794,972**

In order to identify how the low-carbon technologies and renewable energy sources should be prioritised, the cost of carbon abatement has been calculated for each technology. The costs for the electricity, heat and road transport sectors are set out in the tables below and have been used in the pathways to allow the most cost-efficient means of decarbonisation to be adopted first. In general, the options used to decarbonise road transport represent the best value for money in terms of carbon reductions, however it should be noted that these values are based on a cost of ownership analysis and don't take into account infrastructure costs. They also only consider the variation in cost in comparison to a fossil-fuelled counterfactual. These are followed by large-scale renewable electricity generating technologies, district heating (which also provides significant storage to enable greater renewable electricity use) and finally heat pumps. It should be noted that these carbon abatement costs vary for each small area based on local conditions and in some areas DH is more cost effective than other technologies outlined.

The methods used for calculating these carbon abatement costs is discussed in greater detail in Appendix F of this report.

Table 19: Cost of Carbon Abatement in the Electricity Sector up to 2050

Technology	€/MWh	€/tCO_2 Abated
Offshore Wind	65.6	-55.0
Onshore Wind	52.9	-94.0
Utility-Scale Solar PV	50.6	-101.1
Closed-Cycle Gas Turbine	97.8	N/A
Open-Cycle Gas Turbine @ 500 hours	228.9	N/A
Open-Cycle Gas Turbine @ 2000 hours	157.6	N/A
Building-Integrated Solar PV	131.1	147.0
Current Generation Mix (2019)	83.4	N/A

The cost of carbon abatement for the heating sector are set out in the table below. It should be noted that the abatement costs in this table are median figures and will vary for each small area depending on the estimated infrastructure requirements, number, size and demand of each building etc.

Table 20: Cost of Carbon Abatement in the Heat Sector[123]:

Technology	€/tCO_2 Median 2050
District Heating	150.6
Heat Pumps	263.9

The table below shows the cost of carbon abatement calculated for road transport modes, from a total cost of ownership perspective, and represents average values over each period. The transport figures below are based on the CO_2 savings compared to a counterfactual diesel equivalent. For active travel, these figures are relative to car or van travel and are normalised to account for annual distances typically travelled by each mode. The cost analysis considers any additional purchase cost over a diesel alternative (or savings for active travel), as well as maintenance and fuel costs over an initial ten-year period. The costs exclude any government subsidies, and do not consider infrastructure costs.

[123] Assuming discount factor of 2%

Table 21: Cost of Carbon Abatement for Road Transport to 2030 and 2050:

Low-carbon Alternatives	Up to 2030 €/tCO_2 Abated	Up to 2050 €/tCO_2 Abated
BEV Car	- 379	- 649
BEV LGV	- 209	- 288
BEV HGV	179	- 313
BEV Bus	- 22	- 220
Walk	- 7,982	- 7,904
Cycle	- 6,011	- 5,955
E-bike	- 3,760	- 3,625
E-cargo bike	- 926	- 910

The table below provides a comparison of the technology options within the heat and electricity sectors. It should be noted that although renewable electricity is significantly lower than fossil fuel generation the market structures which set the price of electricity are based on the cost of the most expensive generator used (marginal cost), hence these lower electricity costs possible with renewable technologies may not be seen by the customer under current market conditions.

Table 22: Low-Carbon Pathway to 2050

Sector	Technology	GWh Generated or Saved	€/tCO2 Abated (incl. eq. CO2) up to 2050	Avoided carbon taxes € up to 2050	No. of Direct Jobs by 2050	Affordability - Unit price for customer €/kWh
Electricity	Offshore Wind	10,761	(55)	10,106,806	5,217	Dependent on market structure
	Onshore Wind	267	(94)	250,551	235	Dependent on market structure
	USSPV	1,057	(101)	967,621	5,043	Dependent on market structure
	Building Integrated PV	270	147	234,600	3,908	Dependent on market structure
Heat	District Heating	8,926	151	4,151,013	126,266	5% - 10% Lower than alternative
	Heat Pumps	1,397	264	1,387,758	11,078	0
	Gas Boiler (for comparison only)	N/A	N/A	N/A	N/A	0
	Building Fabric Upgrades	1,140	3,127	367,146	30,780	N/A

Interaction Between the Sectors

The diagrams below show how each sector interacts with each other for 2030 and 2050. They show the flow of electricity for use in the heat and transport sectors, the energy storage that can be provided to the electricity sector by the heat and transport sectors, the energy demands in each sector, the impact of energy efficiency etc.

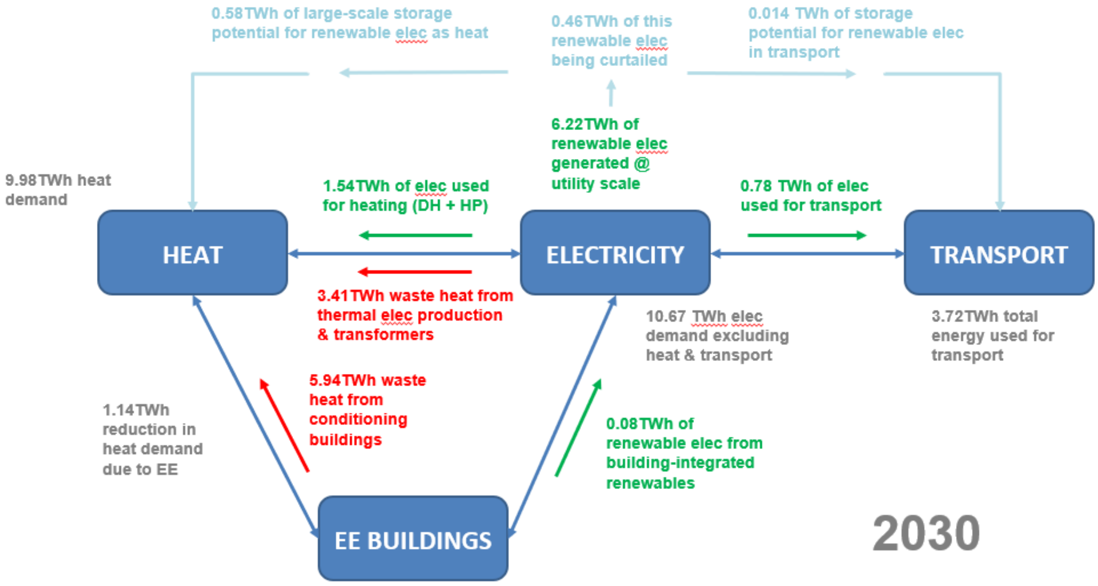

Figure 60: Energy Sector Interaction in the Dublin Region in 2030

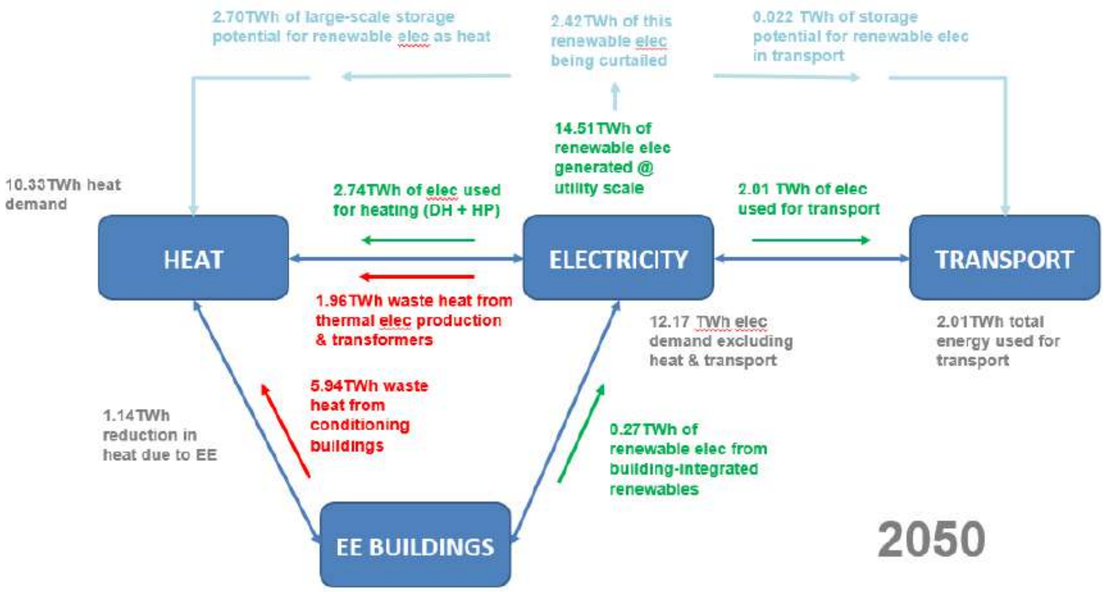

Figure 61: Energy Sector Interaction in the Dublin Region in 2050

Socio-Economic Benefits of the Pathway

Based on the proposed low-carbon and net zero pathways outlined in this document, Codema carried out an assessment of the potential carbon, economic and social impact of this research. The results (which are discussed in greater detail in **Appendix F Socio-Economic Impacts**) of this assessment highlight the carbon saving, renewable energy generation and the economic and social impact of the recommendations. This impact assessment includes a quantitative and qualitative analysis of the socio-economic impacts using key performance indicators in areas such as job creation as well as economic, environmental and health benefits.

It should be noted that the low-carbon and net zero pathways highlighted in this report showcase the opportunities to increase renewable energy and reduce emissions within the Dublin Region. By making use of low-carbon technologies and increasing renewable energy, this can provide multiple opportunities – by using indigenous, sustainable sources to meet Dublin's energy needs, the region can reduce its reliance on fossil fuel imports, and by making use of local solutions to reduce emissions, it can help generate more employment for Dublin's citizens. Employment generation in the low-carbon, clean energy industry would mean that a number of citizens would need to be upskilled for the new roles. By ensuring that citizens are upskilled in the area of energy generation and low-carbon technologies as Dublin transitions to a clean and healthy region, this can ensure a more just transition for the Dublin Region's citizens.

Improving Dublin's built environment and helping to facilitate energy efficiency improvements in the housing stock can directly reduce energy demand and emissions, as well as impact home-owners' and tenants' utility bills, and can help reduce fuel poverty. By improving the heating sector and ensuring adequate low-carbon heating infrastructure is in place to meet Dublin's long term decarbonisation goal, the heating sector can help reduce emissions, create jobs and can provide citizens with warmer homes. By expanding EV charging infrastructure in strategic locations and investing in cleaner modes of public transportation, the region can reduce pollutants from the transport sector. Furthermore, providing safe, attractive and prioritised active travel routes will help encourage more cycling and walking, which benefits both the mental and physical health of citizens.

'A healthy population is a major asset for society, and improving the health and wellbeing of the nation is a priority for the Government and the whole of society. This means that all sectors of society and the whole of Government need to be proactively involved in improving the health and wellbeing of the population'[124].

As the above quotation from Ireland's framework for health and well-being indicates, health policy has increasingly shifted from a narrow focus on health service provision and treating those in ill health to a 'whole systems' approach to health and well-being. This approach recognises the importance of social and environmental determinants of health and well-being, which, in turn, necessitates a whole-of-government and whole-of-society response to embed health and well-being within a range of policy sectors.

Improved Air Quality & Reduced Air Pollution

Air quality is a measurement of the concentration of specific pollutants harmful to human health. Air quality policy focuses on the reduction of pollutants, both GHGs and the more immediate, harmful particulates and dioxins. Reducing the concentration of GHGs means lessening or eliminating the use of carbon-based fuels and moving to renewable sources of energy and carbon sequestration by green infrastructure.

The Environmental Protection Agency (EPA) has stated that **'***Ireland's air quality currently is good, relative to other European Union (EU) Member States, but maintaining this standard is a growing challenge.*'[125] Ireland's monitored air quality is within EU limits; however, despite this, the levels of particulate matter have become a growing concern. During the colder winter months, air quality and health is impacted by increased fossil fuel burning and in Dublin we face potential exceedance of nitrogen dioxide limit due to heavy reliance on private motor vehicles. Even though the air quality in Ireland is generally good, there are, however, localised issues in certain cities. This is the case in Dublin, when in 2019 there was an exceedance of the EU annual average legal limit values at one urban traffic station in Dublin due to transport pollution. The EPA states that the indications show that Dublin will exceed EU limit values for NO_2 at further monitoring stations in the future, therefore reducing pollutants is essential. Even though new standards for car emissions have resulted in cleaner fuels and technology has reduced emissions, Ireland has still seen an increase in both the number and cars and their engine sizes.

[124] Healthy Ireland Framework 2019-2025
[125] https://www.epa.ie/irelandsenvironment/air/

The pathway to net-zero emissions, proposed by this masterplan, will seek to reduce our emissions to the atmosphere by a total of 4,103 ktCO_2 by the year 2030 and 8,240 ktCO_2 by 2050, which will at the same greatly reduce emissions of other harmful pollutants and improve air quality in the county. The World Health Organisation (WHO) estimates that more than 400,000 premature deaths are attributable to poor air quality in Europe annually and has described air pollution as the 'single biggest environmental health risk'.[126]

Air pollution has put an increased risk to our environment and health, with the most vulnerable more likely to be at risk. In Ireland, the number of premature deaths attributable to air pollution is estimated at 1,300 people and is mainly due to cardiovascular disease resulting from exposure to fine particulate matter, $PM_{2.5}$.[127] The economic impact is also significant, with the increased costs of healthcare and lost working days.

Reducing Costs

Besides reducing emissions, technologies recommended in this report help increase renewable energy and lower energy costs. From the pathway outlined in this document, the Dublin Region can potentially generate 14,780 GWh of renewable energy by 2050. This increase in renewable energy can greatly help reduce the Dublin Region's heavy reliance on fuel imports and make use of indigenous renewable resources.

Besides an increase in local renewable energy, these renewable technologies (onshore and offshore wind, USSPV and building integrated solar PV) can decrease energy costs by a total of €519 million per year. Solar PVs help reduce the unit cost of electricity from 24c/kWh to 11c/kWh[128] and wind can reduce the unit cost to 21c/kWh. District heating networks can help reduce heat costs for customers by around 5-10% on counterfactual costs. Installation of heat pumps (have a 300% efficiency, whilst gas boilers are 85% efficient) and building fabric upgrades help improve buildings' efficiency; upgrades also reduce heat losses, which result in reduced heating demands and costs.

In the transport sector, research has shown that walking benefits society to the value of €0.37 per kilometre travelled, while cycling benefits individuals and society by up to €1 per km. This cost-benefit-analysis takes into account parameters such as health impacts, GHG and local air pollutants, noise pollution, land use and infrastructure, travel time and congestion.[129] As mentioned earlier in this report, figures published by the AA suggest that the annual cost of running a family car in Ireland is approximately €10,700 per year.[91] Recent research carried out in Germany similarly found that the cost of running a car there ranged from €6,700 per year to €12,900 per year.[130] This just represents the cost to the individual, and does not factor in external costs. The same German study found that the external social costs of car ownership come to approximately €5,000 per year on top of this, or €0.32/km for a typical family car. Assuming a similar value would hold true for Dublin, cars could be incurring a societal cost of up to €2.8 billion per year on the county at present. On the other hand, walking and cycling currently save Dublin over €258 million per year. Getting more people out of cars and on to active travel or public transport could therefore result in huge societal benefits for Dublin.

Energy cost reductions incurred from improved building fabric upgrades and low-carbon heating technologies can help to reduce areas that are in or at risk of fuel poverty. Fuel poor households are households whose fuel costs are above the household's income; this can be due to an inefficient dwelling, resulting in high energy bills, and low income.

[126] https://www.epa.ie/environment-and-you/air/
[127] EPA, Air Quality in Ireland 2019

[128] Ricardo Energy & Environment, 2020. Economic and Policy Advice to Support Design and Implementation of the New Microgeneration Support Scheme in Ireland
[129] https://www.sustrans.org.uk/bike-life/bike-life-dublin-metropolitan-area
https://www.researchgate.net/publication/330184791_The_Social_Cost_of_Automobility_Cycling_and_Walking_in_the_European_Union

[130] https://www.sciencedirect.com/science/article/pii/S0921800921003943

Therefore, improvements in the housing stock and low-carbon, energy efficient technologies are essential to reduce energy demand in energy poor areas.

The map below displays the outputs of the CSO 2016 Deprivation Index (DPI) Results coupled with BER and Population Data at Electoral District level. The DPIs are constructed using 10 key socio-economic indicators. The scores are then labelled accordingly as > 30 - Extremely Affluent, 20 to 30 - Very Affluent, 10 to 20 - Affluent, 0 to 10 - Marginally Above Average, -10 to 0 - Marginally Below Average, -20 to -10 - Disadvantaged, -30 to -20 - Very Disadvantaged , < -30 Extremely Disadvantaged. To identify energy poverty areas, BERs with a D1 rating or less have been coupled with high unemployment levels (greater than 20%) and a DPI of less than -10 (disadvantaged).

The areas identified as at risk of energy poverty (listed below and shown in red on the map) should be prioritised for energy efficiency upgrades and investment schemes to finance energy efficiency measures needed to alleviate energy poverty. This will benefit the area with their improved quality of life, especially for the vulnerable and can help ensure a more just transition for all.

Electoral districts identified as at risk of energy poverty:

- Ballybough A
- Cabra West A
- Cabra West B
- Clondalkin-Rowlagh
- Clonskeagh-Belfield
- Finglas North A
- Finglas North B
- Finglas South A
- Finglas South C
- Finglas South D
- Inns Quay A
- Kilmore C
- Priorswood D
- Decies
- Drumfinn
- Inchicore B
- Kilmainham A
- Kimmage A
- Kylemore
- Merchants Quay A
- Merchants Quay E
- Tallaght-Avonberg
- Wood Quay A

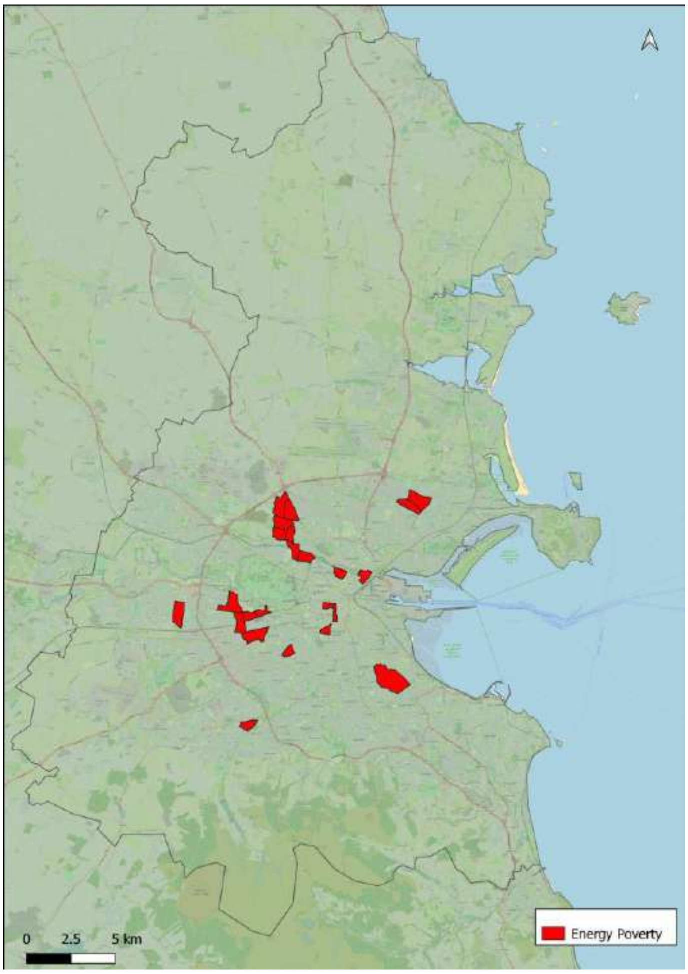

Figure 62: Areas in Dublin Most at Risk of Energy Poverty

Shadow Price of Carbon

The shadow price of carbon is the estimated abatement cost for Ireland to remove emissions from the atmosphere. It is used to account for external costs from GHG emissions. The shadow price of carbon has become more important now due to legally binding GHG emission reduction targets and so it is imperative that the assessment of projects include an appropriate valuation of the cost that society will bear in dealing with the removal of GHGs rising from the project. The use of a shadow price of carbon has become a standard part of Government project evaluation frameworks globally. It was introduced into the Irish Public Spending Code in 2009 and has been modified periodically.

'A shadow price is a hypothetical cost placed on a commodity that is not ordinarily quantifiable as having a market price…an individual project may not have to pay any direct cost for the greenhouse gas emissions it may give rise to. However, since the country as a whole has legally binding targets to reduce greenhouse gas emissions, the cost of these increased emissions will be a burden on society.'[131]

If we were to apply the shadow price of carbon to the total avoided emissions (from renewable energy generation, low-carbon heating technologies, building fabric upgrades and transport improvements) over the lifetime of the masterplan, this would result in a total avoided cost of over €24 billion. This avoided cost would be better invested in renewable sources of energy, active travel and public transport measures, and energy efficient homes and heating options to provide warmer and more comfortable homes.

Table 23: Total Avoided Costs

[131] DPER, 2019. Valuing Greenhouse Gas Emissions in the Public Spending Code

Year	Shadow price of carbon in €/$ktCO_2$	Emission Reductions in $ktCO_2$	Total Avoided Costs (in million €)
2022	46	444	20.40
2023	52	884	45.97
2024	59	1,325	78.15
2025	66	1,765	116.50
2026	73	2,206	161.01
2027	80	2,646	211.69
2028	86	3,087	265.46
2029	93	3,527	328.03
2030	100	3,965	396.47
2031	105	4,178	438.74
2032	110	4,392	483.15
2033	116	4,606	534.30
2034	122	4,820	588.01
2035	128	5,034	644.29
2036	134	5,247	703.14
2037	141	5,461	770.01
2038	148	5,675	839.87
2039	155	5,889	912.73
2040	163	6,102	994.68
2041	171	6,316	1,080.06
2042	180	6,530	1,175.38
2043	189	6,744	1,274.55
2044	198	6,957	1,377.56
2045	208	7,171	1,491.60
2046	218	7,385	1,609.91
2047	229	7,599	1,740.10
2048	241	7,812	1,882.80
2049	253	8,026	2,030.63
2050	265	8,240	2,183.59
Total			**24,379**

Generating Jobs

Non-energy related benefits are often overlooked in the appraisal of energy efficiency projects. Under the Long-Term Renovation Strategy, Member States are required to provide an evidence-based estimate of expected energy savings and wider benefits. The Energy Performance Building Directive (EPBD) explicitly refers to co-benefits relating to health, safety and air quality, and the Commission's Recommendation (EU) 2019/786 of 8 May 2019 on building renovation goes even further and includes examples of co-benefits relating to the reduction of whole life carbon, labour productivity gains, GDP, increased employment in the building sector, and a reduction in energy imports.

Investing in clean energy projects helps improve air quality through renewable energy generation, reduces emissions and improves economic status through the generation of local jobs to facilitate this. Thus, the demand for renewable energy to meet energy demands and the need for energy security is an opportunity for both innovation and employment.

The table below provides a summary of the jobs generated by the various technology pathways in 2050.

Table 24: Jobs created by various technologies used in decarbonisation pathway

Sector	Technology	No. of Direct Jobs by 2050
Electricity	Offshore Wind	5,217
	Onshore Wind	235
	USSPV	5,043
	Building Integrated PV	3,908
Heat	District Heating	126,266
	Heat Pumps	11,078
	Building Fabric Upgrades	30,780

Solar PV

A study by the International Renewable Energy Agency (IRENA) has shown that around 12 million people in 2020 were employed in the renewable energy sector, and a third of this workforce (4 million workers) are employed in the solar PV industry[132]. Solar has become one of the fastest growing industries in the renewable energy sector, with the main driving force for this growth being the decrease in technology costs, which has led to higher demand. Policies for achieving renewable energy targets set at EU and national levels to meet energy demands and reduce GHG emissions have also been a driving factor.

Using the Irish Solar Energy Association's (ISEA)[133] information on job creation through solar PV projects, Codema estimated that 5,845 jobs could be generated from potential building integrated PV projects in Dublin from 2021 to 2050. Of this, over 3,900 jobs are direct jobs in construction and in the operation and maintenance of the solar PVs, and indirect jobs may total 1,937 jobs.

Utility-scale PV, which in this report has been highlighted as the biggest opportunity for Dublin, can greatly impact job creation. The EU Solar Jobs Report for 2021[134] suggests that utility-scale solar PV (USSPV) jobs contribute between 19% to 38% of solar jobs in the EU. Assuming that USSPV can generate an average of 28.5% per MW of jobs created from rooftop PV, direct jobs created in Dublin would equate to over 5,000 and almost 2,500 indirect jobs from USPV.

[132] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Oct/IRENA_RE_Jobs_2021.pdf

[133] Irish Solar Energy Association. Jobs in Solar PV

[134] EU Solar Jobs Report 2021. Towards Higher Solar Ambitions in Europe https://www.solarpowereurope.org/wp-content/uploads/2021/11/SPE-EU-Solar-Jobs-Report-2021-1.pdf?cf_id=43484

Onshore and Offshore Wind

Onshore wind deployment has a consistently positive impact on the Irish economy and net employment in 2020. SEAI's report on Macroeconomic and Net Employment Impacts of Ireland's Renewable Heat and Electricity Targets in 2020[135] estimated that 4,400 net jobs were created in 2020 in Ireland, of which 2,000 were direct jobs in construction, 500 in direct operations and maintenance and the rest in the supply chain. This is also reflected in the GDP for 2020, which preliminary results indicate could increase by €305 – €585 million as a result of building new wind farms and expansion of the grid.

From SEAI's report on onshore wind deployment,[136] It was estimated that approximately 0.34 jobs per MW are long-term jobs directly created to support operation and maintenance of new wind turbines and in the wider electricity supply sector. This falls in line with the European Wind Energy Association estimates for direct O&M employment in Europe. Using these figures, Codema estimated that 429 jobs could be generated from potential onshore wind projects in Dublin from 2021 to 2050. Of these, 235 jobs are direct jobs in electricity supply and construction, 67 jobs are indirect employment, and investment demand can help generate 83 additional jobs.

Meanwhile, offshore wind can also potentially increase employment potential for this sector drastically. EirWind's Blueprint for Offshore Wind in Ireland 2020-2050[137] suggests that *'6.5-7.3GW of domestic offshore wind development would support between approximately 12,000 and 13,500 direct and indirect jobs in the domestic supply , with a total Gross Value Added (GVA) impact of circa €2bn for the period 2020-2029.'* This means that if we were to apply these figures to this masterplan's potential energy generated from offshore wind (3GW), this would result in over 5,200 direct jobs in the offshore wind industry.

Building Fabric Upgrades and Improvements in Heating Technologies

A research report [138] commissioned by the Energy Efficiency Industry Forum to address job creation potential from the Energy Efficiency Directive, estimates that 19 new direct jobs can be expected when investing €1 million in upgrading the energy efficiency of our building stock in the construction sector. Furthermore, it is suggested that the vast majority of these jobs will be local and non-transferable, which would mean that the vast majority of these local job creation would directly impact the local economy. For a cost of €1,620 million, identified in this report as the cost to retrofit 320,000 buildings, this would mean that a total of 30,780 jobs will be created from building retrofits in the Dublin Region, an average of over 1,060 jobs per year from 2021 to 2050.

Heat pump installation for heat pump ready homes would also further increase the potential number of jobs created. The IEA's[139] 'Job creation through investment in heat pumps in the Sustainable Recovery Plan' has identified that the highest number of jobs relate to manufacturing HPs, which generate four jobs per million Euro spent in HPs, followed by installation and maintenance jobs, which generate two and one job per million euro spent, respectively. For the Dublin Region, the total capital cost of installing 78,128 heat pumps (excluding the building fabric upgrades) is €1.2 billion. This would create the equivalent of 382 direct local jobs per year for the period up to 2050.

[135] SEAI, 2020. Macroeconomic and Net Employment Impacts of Ireland's Renewable Heat and Electricity Targets in 2020

[136] SEAI, 2015. A Macroeconomic Analysis of Onshore Wind Deployment to 2020

[137] EirWind Blueprint for offshore wind in Ireland 2020-2050, A Research Synthesis. https://www.marei.ie/wp-content/uploads/2020/07/EirWind-Blueprint-July-2020.pdf

[138] How Many Jobs? A Survey of the Employment Effects of Investment in Energy Efficiency of Buildings. https://euroace.org/wp-content/uploads/2016/10/2012-How-Many-Jobs.pdf

[139]IEA, Job creation through investment in heat pumps in the Sustainable Recovery Plan, IEA, Paris https://www.iea.org/data-and-statistics/charts/job-creation-through-investment-in-heat-pumps-in-the-sustainable-recovery-plan

District Heating can also stimulate the local economy, where jobs created are in proportion to the extent of the network's overall trench length and heat demand served. It is estimated that approximately 45% of the capital cost of developing DH networks is required for installation of the network and its ancillaries.

This portion of the investment will benefit local workers involved in areas such as civil engineering works, and installation of the plant. In addition to this, as DH predominantly utilises local heat sources to produce heat (rather than imported fossil fuels) a significant proportion of the money customers pay for heating their homes also stays in the local economy. This DH roll out optimised to 2050 would require 2,421.8km of distribution pipework and 4,209.5km of customer connections estimated to cost €5.7 billion. The total capital cost of achieving this target is estimated at €7.7 billion with the majority of this investment staying within the local economy. This would create the equivalent of 4,354 direct local jobs per year for the period 2021 to 2050.

Conclusions

Conclusions for Heat

District heating represents the biggest opportunity in the heating sector in Dublin. District heating represents the most feasible low-carbon heating option for 87% of heat demand in Dublin by 2050, equating to a possible 538,983 homes and 41,394 businesses being heated by this source. Heat pumps are the most feasible option for the remaining 13% of heat demand in Dublin by 2050, potentially serving 72,528 homes and 5,600 businesses.

Heat sources that arise as a by-product of electricity generation, industrial activity, the natural environment or from existing infrastructure are low or zero-carbon and often go to waste. Codema estimates that 3,579 MW of heat is available from these sources (including both low-grade and high-grade heat) that could be utilised via district heat networks in Dublin. This equates to 24,244 GWh of heat per annum, enough to heat over 1.6 million homes. These figures are projected to drop slightly over time to 21,952 GWh in 2030 and 22,413 GWh in 2050. This is primarily due to the reduced use of fossil fuel power plants over this period, as renewable electricity generation gains greater market share. This reduction is offset somewhat by increased availability of data centre waste heat and heat generated from curtailed renewable electricity.

Conclusions for Electricity

Offshore wind represents the greatest renewable electricity generating potential in the Dublin area with an estimated 5,241 GWh of generation by 2030 and 13,124 GWh in 2050. Utility-scale solar PV represents the second biggest renewable electricity generating opportunity in Dublin with potential estimated at 854 GWh in 2030 and 1,057 GWh in 2050 in areas the far north and south of the county. Onshore wind has 130 GWh of potential by 2030 and 325 GWh by 2050 in the upland areas in the south of the county.

Utility-scale solar PV provides the most cost-effective means of generating renewable electricity followed by onshore wind, offshore wind and finally building-integrated solar PV (rooftop PV).

Conclusions for Transport

The high dependency on car-based travel in Dublin presents by far the greatest challenge in reducing energy demand and emissions in this sector. Simply electrifying the existing car fleet would represent a huge missed opportunity to address the disproportionate priority and allocation of public space towards this mode of transport, which is particularly inefficient in urban settings. Reclaiming some of the street space currently allocated to cars would be a far more efficient use of this space and could transform Dublin's public realm, providing space for people and nature.

Active travel is the simplest, quickest and most cost-effective way to decarbonise personal transport, particularly for shorter journeys. E-bikes can significantly increase the range over which active travel is possible, and are now the fastest growing form of electric mobility in Europe.[140] Dublin has huge potential for active travel, if the necessary measures are implemented to encourage a shift away from private car use.

This is a time for courage and leadership. It will be impossible to keep everyone happy during this transition to a fairer, healthier and more sustainable transport system, and our policymakers need to publicly acknowledge that this will be a difficult process of adjustment for some. We have already delayed for so long on sustainable mobility that there are no easy options left, however, any hard decisions made today will be far preferable to the harder decisions which will otherwise have to be made later in this decade.

[140] https://transport.ec.europa.eu/system/files/2021-12/com_2021_811_the-new-eu-urban-mobility.pdf

Policy Recommendations

This section of the report sets out some policy recommendations, which could be adopted in order to enable Dublin to deliver its decarbonisation pathway. The analysis from this report can act as an evidence base for the creation of a detailed, timed, actionable transition roadmap for the Dublin region which brings together key stakeholders to deliver the carbon reduction and socio-economic benefits outlined in this report.

Energy Planning

Energy planning is built on evidence-based forward planning, which is essential to ensure that the local authority area, region or country has the required infrastructure in place to serve both new and existing developments with low-carbon and low-cost technologies. It can help bridge the gap between national policy and local implementation, whilst potentially also enabling multi-level governance. There is a clear interest in local level energy planning in Ireland, but it is not widely carried out and there are no guidelines for local authorities.

In Ireland, there is a great need to bridge the gap between energy and spatial planning. Furthermore, it is vital to consider holistic energy solutions that allow for the integration of different energy systems to allow for more cost-effective solutions, rather than having different solutions or technologies working in isolation. Spatial energy planning at the national, regional and local level will underpin the delivery of challenging medium and long-term national policies and targets for GHG emissions, energy efficiency and renewable energy.

Energy planning in Ireland is primarily focused at national level and there is little integration with spatial planning, particularly at local authority level. Without bottom-up energy planning, the unique energy solutions and synergies available only at a local level are often overlooked. Thus, there is a recognised need to build on city/county-wide development plan energy policies, focusing on more evidence-based and spatially appropriate policies and objectives.

Local level energy planning is key to helping local authority areas achieve 2030 and 2050 emission reduction targets. It is timely to ensure environmental considerations for sustainable development are integrated within the planning system at the earliest opportunity and also to bridge the gap between sustainable energy planning and spatial planning as separate processes.

Therefore, it is recommended that guidelines for local level energy planning are made available to municipalities, with the scope to base energy planning policies and objectives on a robust spatial understanding of the existing and future energy synergies across sectors at a local authority scale.

Moreover, it is also recommended that energy planning becomes a requirement for implementing local level energy plans with clear pathways and long-term commitments to a low-carbon future. The approach of bringing spatial planning and energy planning together in such a way that energy issues are fully integrated into spatial planning projects, is very much needed. At a local level, local authorities in Ireland have to meet a number of legal climate action obligations and targets, and energy planning can help support local authorities to meet these obligations and policy requirements in areas such as:

- ➔ preparation of **County/City Development Plans**
- ➔ identification of **Strategic Energy Zones**
- ➔ assessment of **Decarbonising Zones**
- ➔ preparation of **climate mitigation plans**
- ➔ roll out of **low-carbon infrastructure** (district heating, electric vehicle (EV) charging, etc)
- ➔ **Carbon and energy assessment** of planning applications
- ➔ creation of EU Covenant of Mayors **Sustainable Energy and Climate Action Plans**

In order to support more cost-effective and sustainable development of infrastructure (electricity grid, heat networks, transport infrastructure, etc.) higher building density should be promoted within the county as part of the various local authority county development plans.

A GIS-based database of low-carbon technology installations within the County should be maintained. This should include information on the size, type, grid connection details (where applicable) and energy generation (kW peak, annual kWh) of each installation. This will allow tracking of progress toward targets and updates to allow pathways to respond to future cost fluctuations and account for proportion of identified potential that has been realised

Building Energy Efficiency

To meet the scale of deep retrofit needed for the building sector, a big increase in energy efficiency measures is needed. Overcoming the current shortfall in action and investment requires addressing key barriers, including low levels of awareness among homeowners and occupiers, a lack of information about appropriate retrofit measures and the financial options available to pay for them. Alleviating energy poverty is an important benefit of retrofitting in the residential sector. To alleviate energy poverty, the county should consider prioritising energy efficiency upgrades in areas that have been identified in this masterplan as being energy poor.

Electoral districts identified as at risk of energy poverty:

- Ballybough A
- Cabra West A
- Cabra West B
- Clondalkin-Rowlagh
- Clonskeagh-Belfield
- Finglas North A
- Finglas North B
- Finglas South A
- Finglas South C
- Finglas South D
- Inns Quay A
- Kilmore C
- Priorswood D
- Decies
- Drumfinn
- Inchicore B
- Kilmainham A
- Kimmage A
- Kylemore
- Merchants Quay A
- Merchants Quay E
- Tallaght-Avonberg
- Wood Quay A

These upgrades will provide an improved quality of life for those living in these areas - especially for the vulnerable - and can help ensure a more just transition for all.

Rented accommodation in Dublin makes up over one-third of all dwellings, with over 165,100[141] households living in rented accommodation. Whilst in Ireland it is estimated that almost half of commercial buildings are owner-occupied[142] buildings, with the largest numbers being offices and retail outlets. Legislation is an energy efficiency driver and it can be the means to meet the scale of retrofit that is needed to meet our targets. Therefore, regulatory solutions to tackle

[141] https://data.cso.ie/
[142] Ireland's Long Term Renovation Strategy

the issue of split incentives should be considered, and it is recommended that minimum energy efficiency standards for rented properties are applied and structures should be in place that facilitate landlords to achieve this; this would ensure that inefficient buildings will undergo the energy efficiency upgrades needed. Furthermore, funding mechanisms for energy efficiency upgrades, particularly addressing long payback periods and high upfront costs in both the residential and non-residential sector, need to be addressed. Therefore, incentives and financing solutions for building retrofits should be prioritised in the county.

Forward planning is essential to ensure the necessary heat, transport or electrical infrastructure is in place to serve new developments with low-carbon, low-cost energy. In order to facilitate more accurate forward planning, it is recommended that a simple energy assessment form be submitted with all planning applications. This form should include general information relating to energy use within the development such as annual and peak demand for heat and electricity, floor area, BER, heating system details, details of renewables on site, EV charging details, etc.

In order to increase efficiency across transport, electricity, heating, water and other utilities in accordance with the Regional Policy Objective 7.40, it is recommended that the minimum default density for new developments in the County be increased. In order to support a good[143] public transport network (in both urban and suburban areas) for sites within circa 1km pedestrian catchment of a rail station, Luas line, BRT, Priority 1 Quality Bus Corridor and/or 500m of a Bus Priority Route, and/or within 1km of a Town or District Centre, a minimum density of 70 units per hectare[144] should be encouraged.

Heat

Zoning for District Heating

From this study, we can see that DH represents the most cost-effective option for decarbonising the majority of heat demand in Dublin. One of the main barriers to the roll out of DH networks is demand risk (i.e. the risk that buildings will not connect to the network). Providing greater certainty around the demand that will connect to these networks increases their viability and investability and allows the associated carbon abatement potential to be realised. In order to address this challenge, zones identified as suitable for district heating (i.e. where DH represents the best opportunity for the long-term decarbonisation of an area's heat demand) should require buildings within the zone to take measures to facilitate the roll-out of DH. The analysis in this report can form the basis of identifying these DH zones. This is a policy area that is being investigated by Codema as part of the Decarb City Pipes 2050 project. These provisions made to support DH in these zones may include:

- New developments shall be mandated to connect to new and existing DH networks
- If a DHN is planned to operate in the zone within five years, developments shall be futureproofed for connection as defined in Appendix G and commit to connecting to the network once it is completed in order to gain a temporary Part L derogation from Building Control. If a DHN is planned to be operational five years or more after completion of the development, a low-temperature, low-carbon water-based heating system should be installed as an interim solution. This installed solution shall also be futureproofed for connection to DH at a later date in accordance with Appendix G.
- It is also recommended that buildings that are undergoing major renovations (where more than 25% of the surface area of the building envelope undergoes renovation) and are therefore required to upgrade their heating system if more than 15 years old should connect to a local DH network where feasible or future-proof their systems for connection to a DH network when located in a DH zone.
- Potential waste heat sources (where waste heat is produced as a by-product of a site's primary operations) in these zones shall be incentivised to make their waste heat available for use in existing or planned DH networks. Waste heat owners in these areas shall be obliged to provide details of their waste heat source (available heat capacity, available temperatures, estimated annual hours waste heat is available, coordinates for the heat sources location) to inform heat plans and further DH opportunities in the area. As part of this policy, development proposals for new industrial and commercial developments and large extensions to existing

[143] Public transport accessibility level 4 equivalent or higher
[144] Assuming 3 habitable rooms per unit

premises, where the processes associated with the primary operation of the proposal generates significant waste heat, must:

- Carry out an energy analysis of the proposed development and identify the details of potential waste heat generated and suitability for waste heat recovery and utilisation on site and with adjoining sites, and
- Include heat recovery and re-use technology on site, and
- Include heat distribution infrastructure above or below ground (including future-proofing of the building fabric to facilitate future connection, safeguarding any pipework routes up to the boundary to adjoining sites).

or

- Provide evidence that heat recovery and distribution has been fully explored and is unfeasible.

Update Part L of the Building Regulations

Part L of the Building Regulations and assessment methodologies shall be updated to accurately reflect the benefits of renewable heating technologies, waste heat and district heating. Waste heat should be treated on a par with renewable heat sources as outlined in Articles 15 and 23 of the EU Renewable Energy Directive.

Financial Support for District Heating Infrastructure

As a capital intensive piece of infrastructure, district heating networks will require initial upfront capital investment for their development. Financial support from the Climate Action Fund has already provided vital funding for two DH networks in Dublin. The total cost of developing district heating across Dublin by 2050 is estimated at €7.7 billion[145]. The majority of this investment (€4.1 billion) will go to local workers working on the installation of the network providing 4,354 local direct construction jobs. Once built, the network will also create a new local heat market estimated at €959 million per year in 2050. Much of this money previously would have left the country to pay for imported fossil fuels but which could now support new permanent local jobs.

Given the ability of district heating networks to contribute significantly to Ireland renewable heat targets under the Renewable Energy Directive, DH should be eligible to earn renewable heat credits under the proposed Renewable Heat Obligation scheme. This could support low-carbon infrastructure and technologies such as deep geothermal, which are not currently supported under other support mechanisms such as the support scheme for renewable heat. District heating also addresses the issue of "renewable fuels need time" as they are a proven, investable low-carbon heating technology that are already being delivered and don't require the waiting for the development of alternative fuels such as green hydrogen (which has a number of challenges to overcome before becoming a viable option - as outlined in the Green Hydrogen section of Appendix C). Codema has provided more detail on this in a consultation submission[146] on this topic. This revenue stream would also mobilise private sector money for the development of DH networks.

Local Heat Planning to be Mandatory

In line with the EU Energy Efficiency Directive, local heat planning should be mandatory for areas with 50,000 inhabitants or more and the data required to perform this should be made easily available to complete this heat planning. This will allow the best technologies for each city to be identified based on their local characteristics in relation to energy supply and demand, constraints and synergies. This data may also help advance the development of energy masterplans by Sustainable Energy Communities (SECs) for these areas.

Heat Pump Heat Loss Threshold for Grant Support to be Reviewed

Current grant schemes for heat pumps require the building to have a heat loss index (HLI) of less than two. This requires significant additional investment for any heat pump option. Further research into what an appropriate new threshold might be could be furthered through greater interrogation of the Irish Building Stock Generator developed as part of

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[145] This includes customer substations and individual building connection pipework

[146] https://www.gov.ie/pdf/?file=https://assets.gov.ie/204794/50fbf420-af6f-4b9e-9a79-2c84209820ad.pdf#page=null

this study. The purpose of this analysis would be to investigate an increase in the allowable heat loss index to allow more homes to be eligible for support but without exceeding limits that would result in poor heat pump performance.

Customer Protection Regulation for DH

As a new utility, DH is currently unregulated. The adoption of regulation to ensure customers are protected is an important step in ensuring particularly in cases where DH developments are not publicly led and therefore may not have the same focus on the interest of citizens (customers) as a publicly-led scheme may have.

Capacity Building

Both heat pump and DH sectors require significant capacity building across their supply chain. Resources should be made available for those working in planning, construction and installation, design, finance, legal, policy and regulation to be trained and gain practical experience from highly competent experts to achieve the decarbonisation of the heat sector. The provision of staff resources shall also need to be made available and funded. This will ensure the necessary full-time roles needed to deliver the potential outlined are filled.

Support the Adoption of Business Models which Ensure Ongoing Efficient and Reliable Operation of Low-carbon Heating Systems

Encourage the use of heat delivery models (such as Heat as a Service models), which provide designers and installers with greater incentives to ensure efficient and reliable operation of low-carbon heating systems over their lifetime. This can address the current issue of poor performance in one-off installations by linking this design and installation work with ongoing performance monitoring. This may require the coming together of designers and installers under an umbrella organisation, which can underwrite poor performance which standalone installers may not be able to cover under their existing professional indemnity cover and ensure greater competency in these areas.

Electricity

The development of renewable electricity generating plants (in the areas identified as most suitable in this study) and supporting grid infrastructure (transmission and distribution network, conversion stations, storage etc.) should be supported by the national and local planning authorities where possible. Due to their potential scale in Dublin, offshore wind projects in particular will likely require significant land for power quality equipment at the connection point with the electricity grid. The grid itself is also likely to require upgrades in order to avoid unnecessary dispatch down caused by grid constraints.

In order to maximise the use of renewable electricity (limit dispatch down) the provision of grid services (grid balancing, frequency response, etc.) via other sectors particularly via heat networks should be supported. Heat networks provide a particularly good opportunity in this regard due to their cost efficient energy storage potential.

Data centres represent a significant electrical demand in Dublin (4,815 GWh by 2050). In order to ensure that the carbon impact of this electrical consumption is minimised, it is recommended that data centres and other significant electrical consumers take a number of actions to reduce adverse climate impacts. These may include:

- Ensuring that on-site renewable electricity production is maximised where possible. For any remaining electricity demand, this shall be supplied through renewable electricity power purchase agreements (PPAs) which finance renewable electricity developments within the island of Ireland or within its territorial waters. It is also becoming more commonplace to ensure the renewable power purchased is matched to the hourly consumption of these sites to more closely reflect reality (compared with annual matching for production with demand).
- Ensuring that the waste heat produced on site by servers, on-site power generation, etc. be characterised and made available for use for planned or existing DH networks in the area. This has the added benefit of reducing the electrical and water consumption of the data centre cooling system. Further details in relation to the use of data centre waste heat for DH can be found in the policy recommendation paper produced by Codema in conjunction with other DH and data centre industry representatives here.

- Ensuring that data centres impact on the grid is limited. This will be assessed by relevant parties such as EirGrid in accordance with Data Centre grid connection processing procedure[147] to ensure that grid integrity is maintained.

Transport

The measures outlined as recommended for Dublin in the Five Cities Demand Management Study Delivery Roadmap should be progressed as urgently as possible, with the long-term measures fast-tracked where possible for implementation by 2030. This includes measures such as the creation of 15-minute neighbourhoods and low-traffic neighbourhoods, progresssive vehicle taxation including for heavier vehicles, a targeted reduction in on-street car parking spaces, congestion charging, and clean-air zones or car-free zones.

Transport policy needs to pivot towards smaller, lighter and more energy efficient modes and better integration between public transport and active and e-mobility. The Greater Dublin Area Cycle network needs to be completed in full and targets for the number of e-bikes and e-cargo bikes should be set for the Dublin region in order to facilitate their adoption. Shared public bicycle and e-bike schemes should be expanded to cover a greater area of the county. At present, there are significant gaps in urban Dublin, with virtually all of the Dublin Bikes stands located within the Canal Cordon, and the urban areas in the southwest of the county particularly poorly served by private operators. Licensing of any dockless e-scooter schemes will require very careful consideration due to their potentially high lifecycle emissions, the creation of additional street clutter and their tendency to replace existing zero-or low-carbon transport modes such as walking.

Dublin local authority staff and elected representatives should be strongly encouraged to undertake study tours to regions with successful active travel strategies, such as the Netherlands, to see first hand how transformative strong policy and high-quality infrastructure can be on citizens' lives. Such tours have been conducted by some members of the Dublin local authorities in recent years, with the learnings now beginning to be reflected in high-quality new active travel projects across the county.

Ambitious targets need to be set for the reduction in the number of cars licensed in Dublin - this may need to be in the range of 45,000 by 2030 in order achieve a 51% reduction in CO_2 emissions. New grant schemes could be introduced to encourage the shift away from private cars. A more equitable and accessible grant scheme should be introduced for all types of bikes and e-bikes to replace the Cycle-to-Work scheme, which should also include grants to businesses. Similarly, grants should be introduced to encourage people to trade in their cars in exchange for public transport or active travel credits.

EV charging infrastructure needs to be provided in a manner which does not prioritise private motor vehicles over active travel or public transport users and facilitates the goal of a significant reduction in the number of cars on Dublin's roads. It is estimated that up to 4,600 rapid (50-150 kW) charge points will be required by 2030 to meet the demands of 213,000 BEVs.

Existing Government policy calling for at least 50% of new housing in Dublin to be within the existing urban footprint of the city needs to be reinforced and prioritised, with particular emphasis on areas where high-capacity public transport already exists, rather than greenfield sites along motorway corridors.

Goods vehicle traffic volumes are expected to increase significantly over the coming decades. Electrification will be the preferred option in the long run, but until costs reduce later in this decade, the focus should be on freight logistics management, 20% biodiesel blending as per the CAP 2021, and a shift to rail freight for longer distances and e-cargo bikes in urban settings.

Existing road traffic regulations need to be enforced, particularly those relating to illegal parking, speeding, overtaking of cyclists, and driving in bus lanes. This will require appropriate funding and resourcing, with clear allocation of responsibility between the local authorities and An Garda Síochána. Without enforcement, private motor vehicles will

[147] https://www.cru.ie/wp-content/uploads/2021/11/CRU21124-CRU-Direction-to-the-System-Operators-related-to-Data-Centre-grid-connection-processing.pdf

continue to block access to vital infrastructure and the billions planned to be spent on bus lanes, cycle tracks and pedestrian improvements in the coming years will have been in vain. Technology should be used where appropriate, such as the use of automatic number plate recognition (ANPR) systems on buses. A web portal should also be created, where footage of dangerous road behaviour can be uploaded and reported to the Gardaí, as successfully demonstrated in neighbouring jurisdictions, including the UK.

Socio-Economic

Managing social risk is what concerns many policy makers at the European, national and regional levels. Therefore, a key recommendation would be that all existing and new policies should consider the wider social and economic impacts when being assessed for implementation. By assessing all policies in relation to wider economic, social and health impacts at local level, the Dublin Region will be able to make a very strong case for scaling investment in programmes that are most beneficial to local communities, with the aim of improving the economic, health and social aspects of Dublin's citizens.

Additional policy recommendations include the promotion of skills and education in the energy efficiency sectors, promoting smart technologies and well-connected communities, and awareness raising. By promoting upskilling and education in the different sectors, this ensures that there is a skilled and knowledgeable workforce equipped for the increase in the roll-out of low-carbon and renewable energy technologies and enabling infrastructure. This also provides employment opportunities for those currently working in fossil fuel-dependent sectors, which are likely to contract as we transition towards a lower carbon economy, thereby ensuring a more just transition for all. It is important to raise awareness on the benefits of these technologies to citizens, making sure that they have a good understanding and are central to any changes proposed. This will help increase the uptake of renewable technologies as well as improve their financial viability (through economies of scale) and help with the reduction of energy use and emissions, thus improving air quality and in turn improving citizens' quality of life as well as providing local employment opportunities.

The county may also consider prioritising investment in local community low-carbon and renewable energy projects; helping communities to take ownership of such projects will benefit the community financially and with their quality of life, especially for the vulnerable. These local projects can also help improve air quality whilst bringing citizens together and instilling pride in their community. This may include a mechanism whereby citizens of Dublin are given first preference on a minimum percentage stake in local renewable and low-carbon energy projects.

Further Research

Topics for further research, identified throughout this masterplan process, are shown in the table below:

Table 25: Topics for further Research

No	Topic	Sector
1	Refrigerant leakage from large-scale heat pumps vs domestic heat pumps - How the F-gas regulations differ for both types and what this means in terms of global warming potential from both systems - Check on approach used for DREM	Heat
2	Embodied carbon of common individual low carbon heating systems - perhaps based on TM65 methodology for MEP systems. Use BER database to classify most common or archetype systems to analyse	Heat & Energy Planning
3	Refrigerant leakage from the transport sector (associated CO2 eq.) - AC in passenger vehicles, refrigerated trucks etc.	Transport
4	Decarbonisation strategies for high temperature industrial applications relevant to Dublin (pharma, f&b etc.) - electrification, H2, bioenergy, deep geothermal. Considering quality of each in terms of cost, control, compatibility with existing processes	Heat
5	Qualitative analysis of DH heat sources that builds on quantifying and temp available analysis done in DREM - the relative quality of the heat sources in terms of carbon content, riskiness of different heat sources e.g. deep geothermal is extremely low carbon but has big uncertainty about whether that heat is extractible before you invest in drilling into the ground, or industrial sites have high temps and low CO2 but are at risk of the businesses shutting down, sensitivity in regards to proximity to heat demand.	Heat
6	Land price index is available (see excel spreadsheets in solar folder or https://www.cso.ie/en/releasesandpublications/ep/p-alp/agriculturallandprices2018/rb/) for Dublin as a whole check if this is broken down anywhere - projects such as USSPV should be located on lower value/quality land. Perhaps work using a standardised approach (CPO) for valuing land.	Energy Planning
7	A cross-organisation open source data portal. https://datasette.io lets users explore datasets in the their browser by supporting plotting & querying & joining data, try their demo - https://global-power-plants.datasettes.com/global-power-plants/global-power-plants	Energy Planning
8	Finding the balance in terms of HLI - reasonable heat pump efficiency vs the retrofitting cost to the existing housing stock (using the synthetic building stock model).	Energy Efficiency in Buildings/Policy
9	The impact on cooling from improved energy efficiency - additional energy used for cooling (predominantly from internal heat gains exacerbated by high performing building envelope (low air changes)	Heat
10	Include learning curves in cost estimates for Masterplan. The following reports from the University of Oxford may act as a basis for this analysis: (1) Empirically grounded technology forecasts and the energy transition, and (2) A new perspective on decarbonising the global energy system	Energy Planning
11	Split heat load into SH & DHW in DREM analysis with different HP efficiency for both operations - how does this affect COP in nZEB where a bigger proportion of load forces HP to operate at lower efficiency.	Heat
12	Non-domestic building fabric is very limited, further research on current non-residential building fabric is needed	Energy Efficiency in Buildings
13	Embodied carbon	Energy Efficiency in Buildings
14	Further investigation of funding mechanisms to fund the large scale retrofit of the residential building stock that is needed to meet 2030 and 2050 targets	Socio-Economic/ Energy Efficiency in Buildings
15	Study to identify actual domestic off-street car parking split at small area level - include in Census?	Transport

Appendices

Appendix A - Energy Modelling

The following section explains the development of the energy model, modelling tools considered and data storage and management for the DREM.

As a part of this project process, Codema has prioritised the use of open-source tools in the development of the Dublin energy models. The main motivation for this was to help ensure that the report is interactive and open for use and interrogation by others in order to facilitate a high degree of replicability by other regions within the country. With the main aim being that this masterplan can provide support to further decarbonisation in the near future through evidence led energy planning and policy making.

Resources and maps are readily available online on Codema's Github[148] and Tableau Public[149], which allows the general public to find answers to energy related queries specific to their area, which can help increase engagement with citizens on local level energy planning and climate action. Making useful data available (with some pre-processing completed) was a starting point for this project, which could help further research by wider organisations and academic bodies. This has been the case with Codema's collaboration with the National Residential Energy Modelling Group, over multiple discussions in this modelling group, it was agreed to standardise the process of cleaning residential data and that it would be made available for wider use.

Building Energy Model

It should be noted that this is a very new space in energy research in Ireland. It was found that existing open-source tools are either not designed for Ireland or are only designed to work at an individual building level. In the case of individual building models, it was necessary to bend reality to fit the tool by creating a handful of detailed individual building models and extrapolating these to fit the building stock. The main aim of the residential building energy model was to create a tool capable of modelling different buildings and their energy demands. Furthermore, the building model is required to capture the energy and carbon savings from the energy retrofit of hundreds of thousands of residential buildings, whilst also having the ability to assess the Building Energy Rating (BER) improvement and the cost of each energy retrofit.

As a part of this project, multiple building energy model software was considered in great detail before Codema generated its own building model. For the purposes of this project a new, simple building stock model was created for the Irish building stock[150] to model hundreds of thousands of individual buildings all at once.

Residential Synthetic Building Stock

The synthetic building stock for the residential sector is based on two main data sources, the Central Statistics Office's (CSO) 2016 census and SEAI's Building Energy Rating (BER) Research Tool.

The BER Research Tool was used in this analysis for the calculation of energy required for normal use of space heating, hot water, ventilation and lighting per metre squared area of a residential unit. The final energy rating given to a household is in kWh/m^2/year and an energy efficiency scale from A to G. It also provides an insight into other data, such as type of household, year of construction, location, floor area and fuel use.

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148 https://codema-dev.github.io/

149 https://public.tableau.com/app/profile/rowan.molony https://public.tableau.com/app/profile/oisin.doherty

150 https://github.com/codema-dev/rc-building-model

The census is a mandatory survey of all dwellings and is a complete dataset of the residential housing stock. It includes location, period built and type of dwelling, which is broken down into apartments, terraced, semi-detached and detached. However, this dataset is missing information on specific building characteristics (dimensions, insulation, efficiency of heating systems, etc.), whereas the BER Research Tool contains this information, but is not available for all Dublin dwellings. This occurs because buildings only require a BER if they are for sale or have been sold since 2009, if they are for rent, or if the householder is applying or has applied for grant funding for energy efficiency renovation.

To generate a complete synthetic residential building stock for all of Dublin with characteristics relevant for modelling energy demand and emissions, the census data was replaced with BER building characteristics. Buildings in the BER dataset are linked to the Census by matching two parameters common to each dataset which have the largest impact on predicted energy demand - building period and dwelling type. Buildings that do not yet have a certified BER were assumed to be typical or archetypal buildings. In order to create these typical buildings, it was assumed that buildings located close to one another and built during the same time period also have the same building properties. This synthetic building stock gave Codema a complete spatial analysis for building stock energy demand for cases where little or no building level data is available. Thus, the energy demand for the residential sector, broken down into heat and electricity, could be estimated.

As this procedure is somewhat complicated to implement, a web application named the Irish Building Stock Generator[151] (IBSG) was developed by Codema to automate the creation of a synthetic building stock to enable the wider Irish energy research community to reproduce the DREM building stock, and use it in their own research.

Residential space and water heating demands are estimated from the synthetic building stock which, as explained previously, combines the census 2016 data (which also gathers the household heating sources by small area) and the BER database (which estimates both space and water heating demands for the different dwelling types by period built in each SA).

To generate heat demands, it was assumed that the Dwelling Energy Assessment Procedure (DEAP) model of hot water and space heat demand is indicative of actual usage. Therefore, a typical boiler efficiency of 85% was assumed – this is the typical boiler efficiency of residential properties used in the BER database. Further detail on heat demands can be found in the section **Modelling Building Heat and Electricity** and **Appendix C – Heat Sector Methodology.**

Electricity demands were estimated from the synthetic building stock which included electricity demands from the BER database, this accounted for space and water heating, pumps, fans and lighting. The smart meter trial data was provided by the Commission for Regulation of Utilities (CRU); this gave information about consumers' electricity usage behaviours and has helped to model demands and different times of the day. This is discussed in further detail in the section **Modelling Building Heat and Electricity** and **Appendix D – Electricity Sector Methodology.**

Non-Domestic Buildings

The non-domestic sector includes commercial, public and industrial buildings. The main data source for the non-domestic sector is a detailed list of all rateable commercial buildings which was provided by the Valuation Office. This data includes a list of all the commercial properties, their location and respective floor areas in the Dublin Region. These properties were also broken down into different categories and types of use. The maps below show the number of non-domestic properties in the Dublin Region.

The non-domestic building sector is the most difficult sector to estimate building energy demand due to the lack of data available to develop a more robust methodology. The lack of data in this sector is not specific to Ireland, and provides a challenge which all EU member states will need to overcome. Work on analysing energy use in the sector is ongoing and significant advances in the collection and analysis of data have been made in recent years to improve the understanding of the profile of the commercial sector, energy use and energy saving opportunities. Thus, to estimate

151 https://github.com/codema-dev/rc-building-model

energy demands from non-domestic buildings, a number of different methodologies were used (this is explained in greater detail in **Appendix B – Building Sector Methodology**).

The model makes use of both metered data and theoretical energy demand. For the public sector, metered data was used since public sector bodies are required to report on their annual energy use and performance to the Sustainable Energy Authority of Ireland (SEAI). This is done through the Monitoring and Reporting system (M&R), which is used to track the public sector's progress towards their energy efficiency and emissions targets compared to the baseline year. The energy use for the different public sector bodies is reported in terms of building location, use and metered electricity and gas demands. For industrial buildings, when site-specific annual energy demand data was available on the EPA website through Annual Environmental Reports (AER), these were made use of. The AERs are used to provide a concise summary of licensees' environmental performance; some of the information captured in the AER include the companies' environmental objectives and targets achieved, goals to maintain compliance and summary results from emissions monitoring, which includes energy demands (in kWh) broken down by fuel used. Energy consumption benchmarks from the Chartered Institution of Building Services Engineers (CIBSE) were used for both commercial buildings and industrial (when AER reports were not available). The CIBSE energy figures are only split into either fossil fuels or electricity.

Other avenues were explored, such as establishing benchmarks based on commercial BERs and public sector M&R data; however, these efforts were ultimately abandoned due to data quality issues. The commercial BERs do not contain metered data but rather theoretical demands and cannot be geolocated. Creating floor area energy benchmarks on theoretical demands that cannot be linked back to the valuation office dataset was not deemed worthwhile.

Modelling Building Heat and Electricity

Residential space and water heating demands are estimated from the synthetic building stock which, as explained previously, combines the census 2016 (which also gathers the household heating sources by small area) and the BER database (which estimates both space and water heating demands for the different dwelling types by period built in each SA). To estimate the energy consumption used for heating in the non-domestic sector, it was assumed that for public buildings, all GPRN metered data contributed to heating, whilst for industrial and commercial buildings, that all fossil fuel energy was used for heating.

To generate heat demands it was assumed that the Dwelling Energy Assessment Procedure (DEAP) model of hot water and space heat demand is indicative of actual usage. In order to determine the emissions associated with heat, the following typical heating system efficiencies were used for each heat source used.

Table 26: Heat Source Efficiency

Heat Source	Efficiency
Gas	85%
Oil (Kerosene)	80%
Direct Elec	100%
HP	300%
Wood Pellet Boiler	65%
Stove (soft wood)	65%
Stove (wet wood)	65%
Smokeless Coal	30%
Briquettes	30%
DH	460%

Electricity demands for the residential sector were estimated from the synthetic building stock, which included electricity demands from the BER database, this accounted for space and water heating, pumps, fans and lighting. Whilst electricity demand for the non-domestic sector was estimated from MPRN metered data for the public sector, metered data from AER reports and benchmark electricity figures for the industrial and commercial sector.

Smart meter trial[152] data was provided by the Commission for Regulation of Utilities (CRU); this gave information about consumers' electricity usage behaviours (for both the residential and non-residential sector) and has helped to model demands and different times of the day. This was initially used to estimate diversified peak demands until better information in the form of the ESB special load reading data became available. Whilst this diversity curve was replaced in this analysis, it may still be useful for those looking at determining diversified peak electrical demands for equipment serving sites with fewer dwellings[153] and hence has been included below.

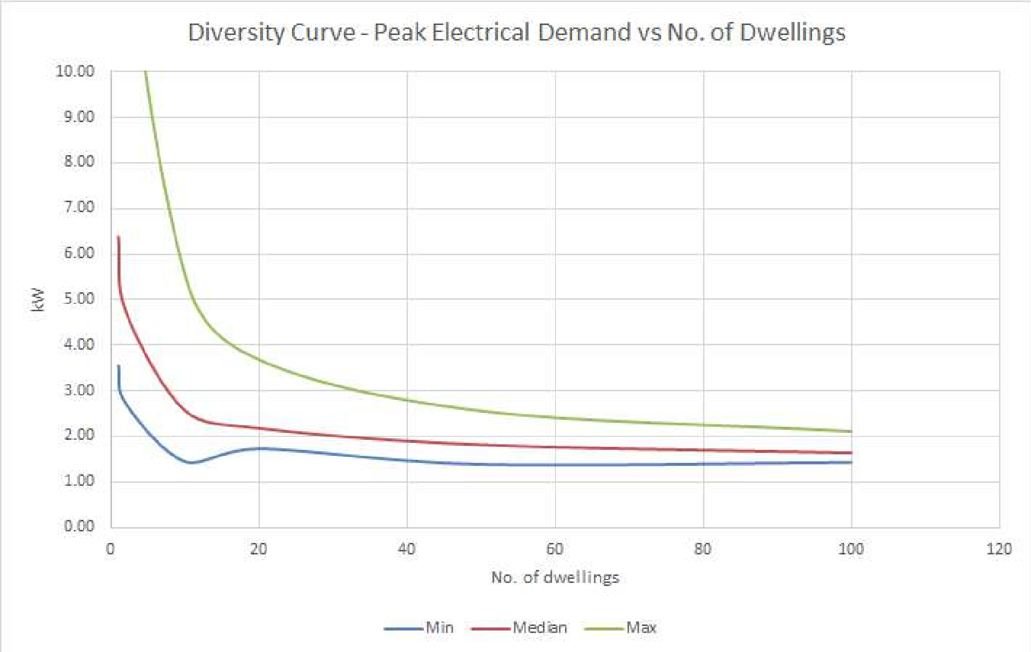

Figure 63: Electricity Diversity Curve

Modelling Retrofits and Carbon Savings

The level of building stock and energy demand information at such spatial resolution allowed for the identification of feasible building fabric upgrades for all buildings. Since building fabric information for non-domestic buildings was very limited, non-domestic building fabric upgrades were not considered. However, improvements in non-residential buildings' energy efficiency due to fabric upgrades (% improvement in energy efficiency) and improvement in heating technologies for this sector are accounted for in the Heat Section and it was assumed that commercial buildings in each small area would have a similar heating technologies as this for the most common residential dwelling in the small area (this is described in further detail in **Appendix C - Heat Sector Methodology**.

Other avenues explored to identify non-domestic building fabric information included the assumption that commercial properties in each small area would have a similar building fabric as the most common residential dwelling in the small area i.e., the commercial buildings would have been built during the same period and using the same building materials and have the same fabric as those found in the residential sector. However, this assumption was not viable as it would have led to other less realistic assumptions to be made on window, roof, and wall areas (so as to generate fabric upgrade costs), thus this assumption was deemed not worthwhile.

In order to improve energy efficiency and reduce emissions from the residential sector, the building energy model was setup in such a way that it can model the impact that building fabric upgrades have on:

- BER ratings
- Heat Pump Viability
- Energy Savings

[152] https://github.com/codema-dev/cer-smart-meter-trials-2009-2011
[153] https://github.com/codema-dev/cer-smart-meter-trials-2009-2011

· Cost by Measure

The model makes use of current buildings' fabric U-values. U-values measure the effectiveness of a material as an insulator, meaning it determines a material's heat loss. The well insulated material will have a low U-value and thus, will lose less heat. The building stock's U-values for walls, roofs and windows determine how much heat is lost through the building fabric. In order to retrofit a building to be able to meet a minimum B2 BER standard, it is necessary to first reduce its fabric and ventilation heat loss by retrofitting it. Detailed information on costs and the methodology used to derive building fabric costs can be found in **Appendix B - Building Sector Methodology.**

Energy Modelling Tools Considered

All of the following approaches have been automated and published using a mixture of open[154] and closed[155] source software[156]. Previously, all the data analysis was performed solely using Microsoft Excel; even though this is useful for small datasets, it soon becomes a burden when working with multiple large datasets. For example, when generating the previous residential energy estimates it was necessary to create up to 16 separate workbooks for each local authority each containing as many as 15 sheets, as the datasets were too large to fit into a single workbook. Although each workbook performed the same logic to clean and merge datasets, changing this logic meant changing all of the separate workbooks one at a time. Moving to open-source tools enabled using logic written down in scripts (or text files) to wrangle and merge data files, thus separating data from the logic operating on it. This means that if any dataset is updated, re-generating outputs is as simple as running a few scripts. Furthermore these scripts can be shared without sharing the underlying datasets (some of the datasets used in this work are only available upon special request). This enables other researchers doing similar work to build on and re-use aspects of this work in their own research.

This is a very new space in energy research in Ireland. It was found that existing open source tools, such as CityEnergyAnalyst, are either not designed for Ireland[157] or are only designed to work at an individual building level (such as EnergyPlus). In the case of the individual building models, it is necessary to bend reality to fit the tool by creating a handful of detailed individual building models and extrapolating these to fit the building stock. For the purposes of this project a new, simple building stock model was created for the Irish building stock to model hundreds of thousands of individual buildings all at once. This will be discussed in the following sections.

All open-source software developed over the course of this project has been made publicly available through Codema's Github[158] to facilitate transparent and reproducible[159] research.

The main aim of the building energy model was to create a tool capable of modelling different buildings and their energy demands. Furthermore, it was also required that the building model is required to capture the energy and carbon savings from the energy retrofit of hundreds of thousands of buildings, whilst also having the ability to assess the Building Energy Rating (BER) improvement and the cost of each energy retrofit.

As a part of this project, multiple building energy model software was considered in great detail before Codema generated its own building model. Some of the system models that were assessed are detailed below. **EnergyPLAN** is

[154] Source code that is made freely available for possible modification and redistribution: Python: pandas/geopandas for data wrangling, ploomber for data pipeline orchestration, bokeh for static interactive maps, streamlit for interactive web applications, Ruby: Jekyll for static website generation, QGIS: static webmaps
[155] Computer software for which the software's publisher or another person reserves some rights from licenses to use, modify, share modifications, or share the software: Github: source code version control, Amazon: s3 for data storage, Tableau: interactive web applications
[156] Closed-source software has been used for data storage and visualisation purposes, and open-source for data wrangling.
[157] Cityenergyanalyst depends upon Openstreetmaps (an open alternative to Google Maps) being of adequate quality. Until more building characteristics are added to this dataset such as building heights and ages, it won't be useful in this context
[158] Website: codema-dev/codema-dev.github.io, Data pipelines: codema-dev/projects
[159] Where our source code does not depend on closed-access data

an energy system model that works well for comparing aggregate demand against renewable supply profiles. However, this does not model individual buildings and instead requires aggregated inputs for building energy demands.

SEAI's **Dwelling Energy Assessment Procedure** (DEAP) Excel model, **EnergyPlus** and **RC_BuildingSimulator** can model individual buildings using simple physics-based simulations but are difficult to scale. As a result, it is necessary to create a limited number of representative archetypes (<100) in order to use them to model building stocks. At present, archetype creation for these models is a long, manual process. To avoid this limitation, some scripting libraries were experimented with to see if this process could be sped up:

- DEAP: *pycel* (a small Python library that can translate an Excel spreadsheet into executable Python code, which can be run independently of Excel) enables replacing individual building characteristics specified in a DEAP Excel model via a Python process. However, as of January 2020, pycel library did not support all operations performed in the DEAP spreadsheet.
- EnergyPlus: enables replacing building characteristics and geometry-specific characteristics via Python. As of September 2020, these libraries were better suited to parameterising existing models rather than creating them from scratch.
- RC_BuildingSimulator, which is a Python library and can be easily scaled up. This library was not made use of as it is not actively maintained, and as such, is cumbersome to adapt to this use case and would require accuracy validation, since it is not a widely used library.

CityEnergyAnalyst also models individual buildings using physics-based simulations but is designed for district-level simulations. However, it is tied to Openstreetmaps as a data source for building geometries and ages and to Swiss building standards by building age for archetypes. As of October 2020, Openstreetmaps was not as complete as in Switzerland, and decoupling CityEnergyAnalyst from it proved to be difficult.

Table 27: Energy Modelling Tools Considered and Barriers Encountered

Tool	Barrier
EnergyPLAN	Models aggregated building energy demands
DEAP	Individual building demands that need to be scaled up for the Dublin Region
EnergyPlus	Individual building demands that need to be scaled up for the Dublin Region
RC_BuildingSimulator	Adaptation and validation needed for the Dublin building stock
CityEnergyAnalyst	Poor quality data for the Dublin Region building stock

As a consequence, Codema developed the rc-building-model, which re-implements the DEAP model in Python. This model was tested and validated against the DEAP Excel model for individual buildings, and implemented to easily and rapidly scale up individual buildings to the Dublin building stock.

Data Storage and Package Management

Since this masterplan involved the use and analysis of large amounts of data, Codema sought to store all this data in a managed system. Thus, all raw data for the DREM is saved on both Google Drive and Amazon s3. Amazon s3 is a simple storage service offered by Amazon Web Services, which at the time of writing, is easier to query from within code than Google Drive. Amazon s3 enables the sharing of data between projects by storing intermediate datasets, which in most cases for the DREM change infrequently. Google Drive is still used for all data manipulated by Excel or QGIS.

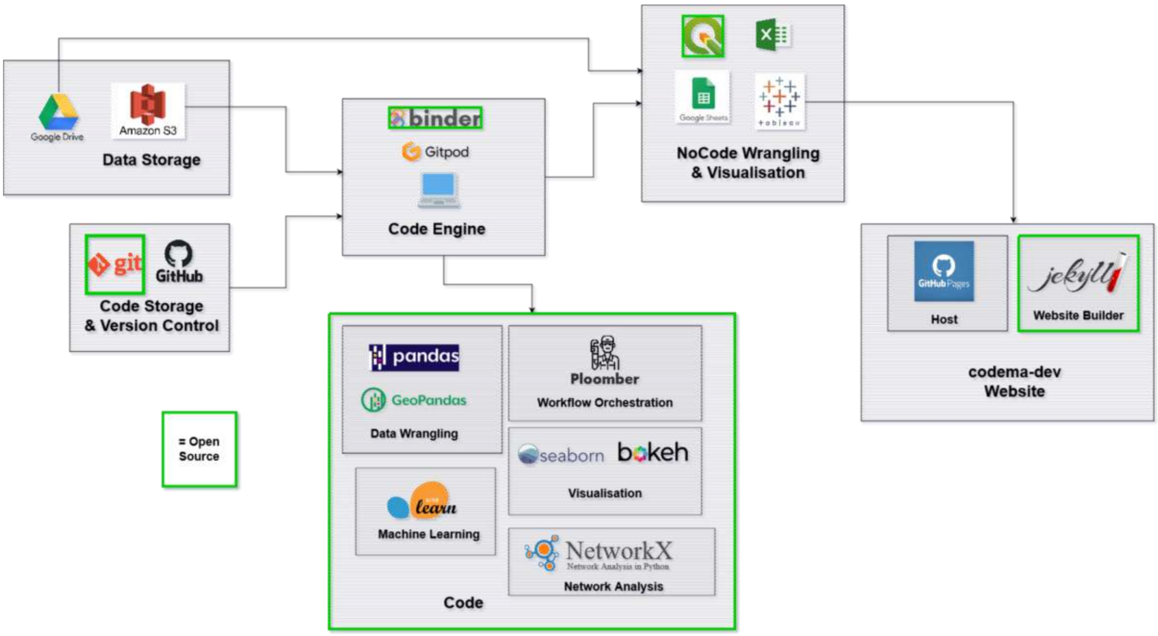

Figure 64: Tools used and Data Storage for the DREM

The figure above shows how all the software used for this project work together and the output of this is that all the code generated for this project is then saved to GitHub which is made publicly available and can be queried by different users.

Code Engine

Getting the code up and running on your local machine can be somewhat involved and code engines such as binder or Gitpod enable running this code on cloud machines for free. They automate the building of the required installations using configuration files, such as environment.yml for binder and .gitpod.yml + .gitpod.Dockerfile for Gitpod.

The software packages used to create and manipulate the code are outlined in the table below:

Table 28: Code Software Packages

Package	Use	Equivalent-To	Example-Use
pandas	Data wrangling, visualisation & analysis	Microsoft Excel	Estimating annual residential heat loss by combining columns and constants
GeoPandas	Geodata wrangling, visualisation & analysis	QGIS	Linking small areas to postcode boundaries
Ploomber	To specify and execute all of the steps that need to be run in order to generate the output datasets or visualisations	-	Downloading and cleaning building data, and plotting district heating viability on a map
seaborn	Plotting charts and maps	QGIS	Plotting building energy ratings
bokeh	Plotting interactive charts and maps	Tableau	Plotting district heating viability on a map
NetworkX	Graph analysis	-	Finding the nearest substation to each region along the nearest electricity line
Scikit Learn	Machine learning	-	Clustering substations via intersubstation distances

Appendix B - Building Sector Methodology

Energy Efficiency in the Building Sector

The following section explains the development of the building methodology and results for all buildings within the boundary of the Dublin Region. This includes all residential, public, commercial and industrial buildings. The best available data was used in all cases, and collaboration with multiple external researchers and agencies has given confidence in the methodology applied.

Current Energy Demand

As described in **Appendix A - Energy Modelling,** the current energy demand was determined from the building sector's energy model. The methodology for the synthetic building stock included data generation for data gaps in the building sector and assessing building energy demands. The following section outlines the data sources, assumptions made and findings for both the residential and non-residential sector.

Residential

Data Sources

The synthetic building stock for the residential sector is based on two main data sources, the Central Statistics Office's (CSO) 2016 census and SEAI's Building Energy Rating (BER) Research Tool.

The BER Research Tool developed by SEAI, was used in this analysis for the calculation of energy required for normal use of space heating, hot water, ventilation and lighting per metre squared area of a residential unit. The final energy rating given to a household is in kWh/m^2/year and an energy efficiency scale from A to G. It also provides an insight into other data, such as type of household, year of construction, location, floor area and fuel use.

The census is a mandatory survey of all dwellings and is a complete dataset of the residential housing stock, it includes location, period built and type of dwelling which is broken down into apartments, terraced, semi-detached and detached. However, this dataset is missing information on specific building characteristics (dimensions, insulation, efficiency of heating systems etc.), whereas the BER Research Tool contains this information, but is not available for all Dublin dwellings. This occurs because buildings only require a BER if they are for sale or have been sold since 2009, if they are for rent or the householder is applying for or has applied for grant funding for energy efficiency renovation.

Estimating Electricity and Heat Demands

The census 2016 captured data on residential heating fuel sources that included natural gas, electricity, oil, coal peat, LPG and wood. Using this source of data, Codema found that natural gas was the predominant heating source in the Dublin Region, accounting for 68% of all households. This was followed by electricity at 14% and oil at 11%. The combined remainder (coal, peat, LPG, wood, other sources, no central heating and not stated) only accounted for 7% of residential heating sources.

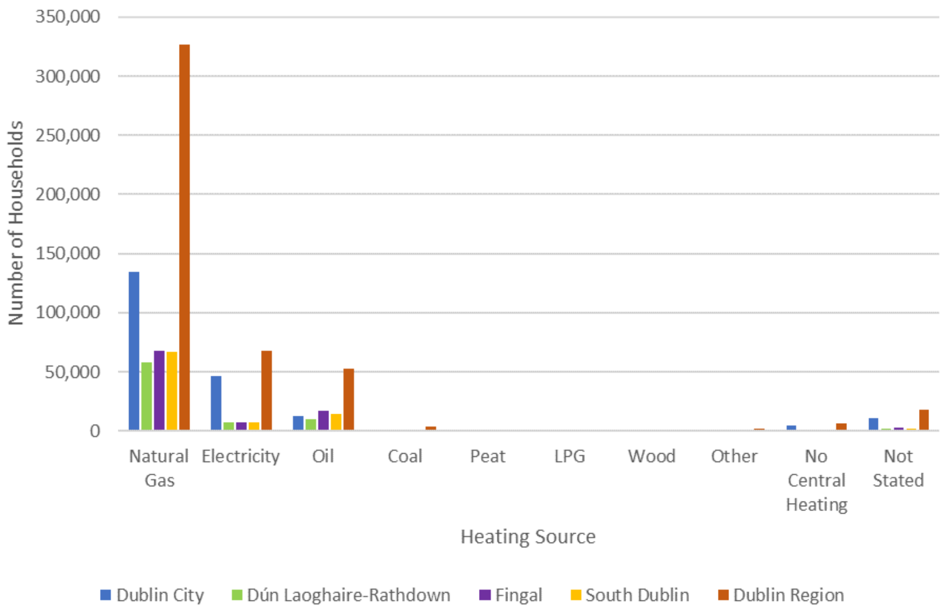

Figure 65: Residential Heating Sources

A small area (SA) boiler map of Dublin's residential buildings can be found on Codema's online website[160], which shows the number of residential buildings in each SA and their heating source (heating sources included are natural gas, electricity, heating oil and heat pumps).

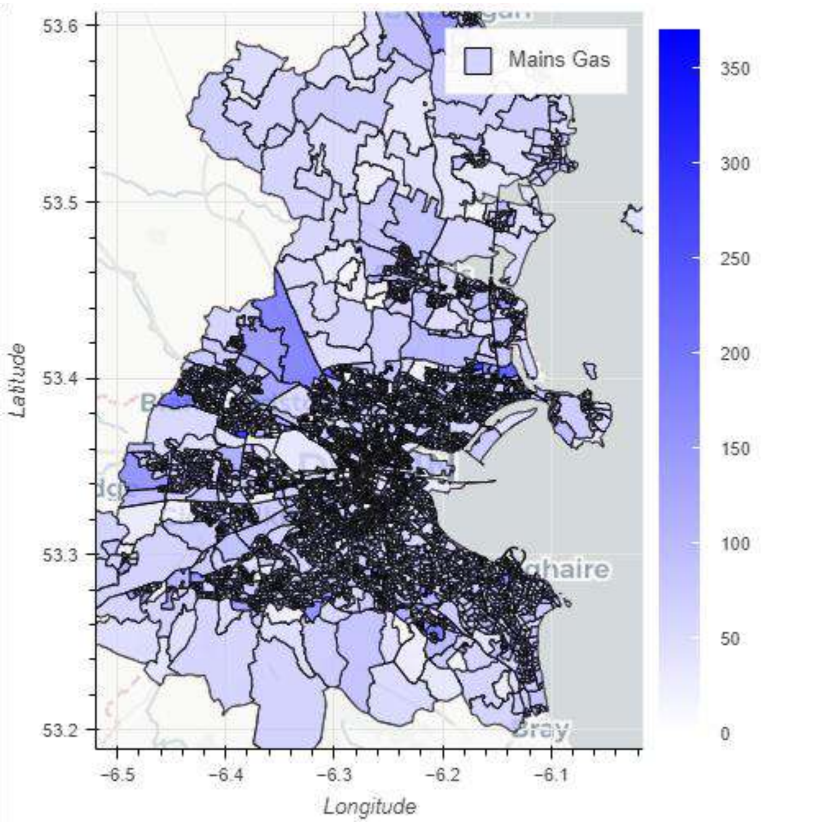

Figure 66: SA Residential Boiler Maps for Natural Gas

[160] https://codema-dev.github.io/map/boiler-maps/

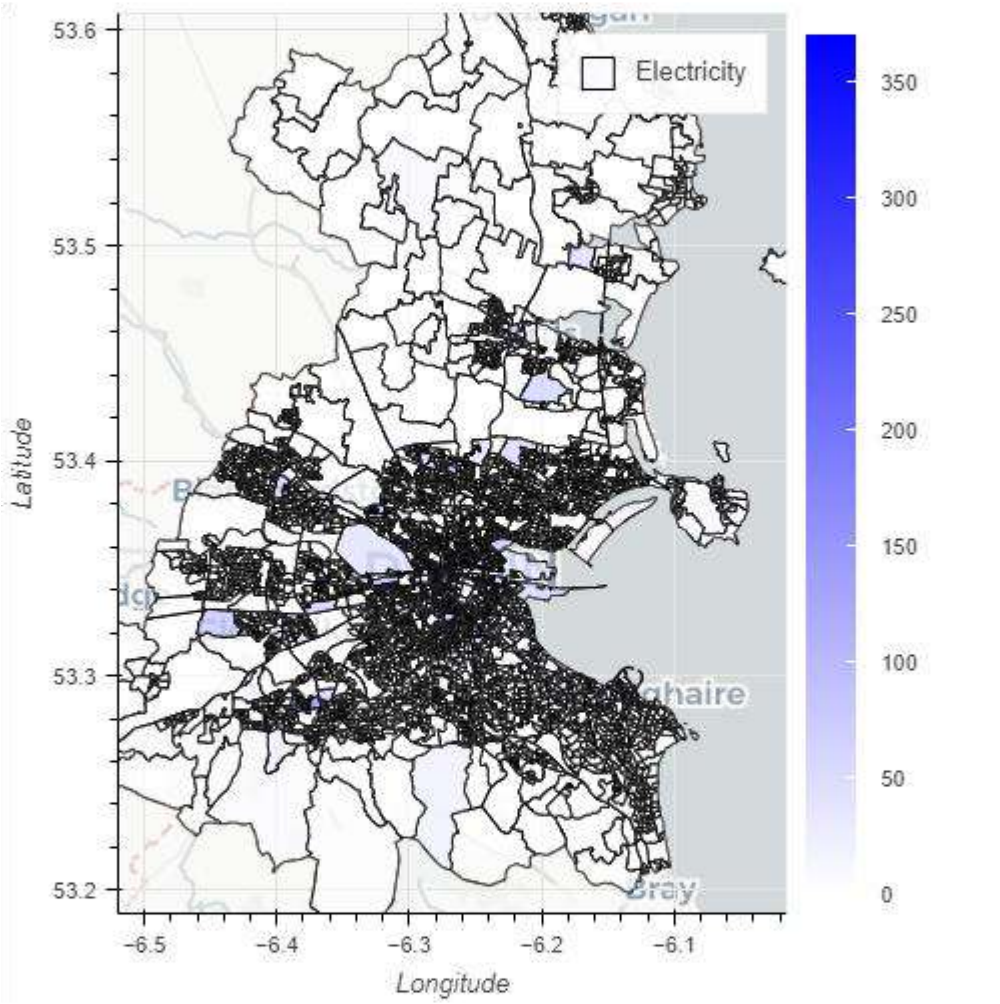

Figure 67: SA Residential Electricity for Heating Map

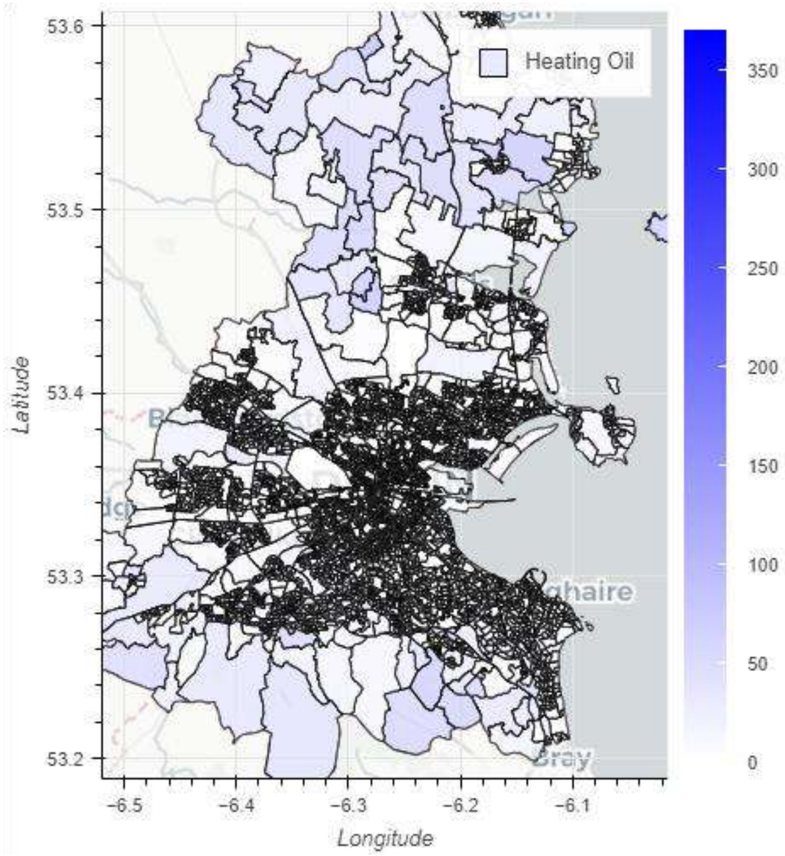

Figure 68: SA Residential Heating Oil Map

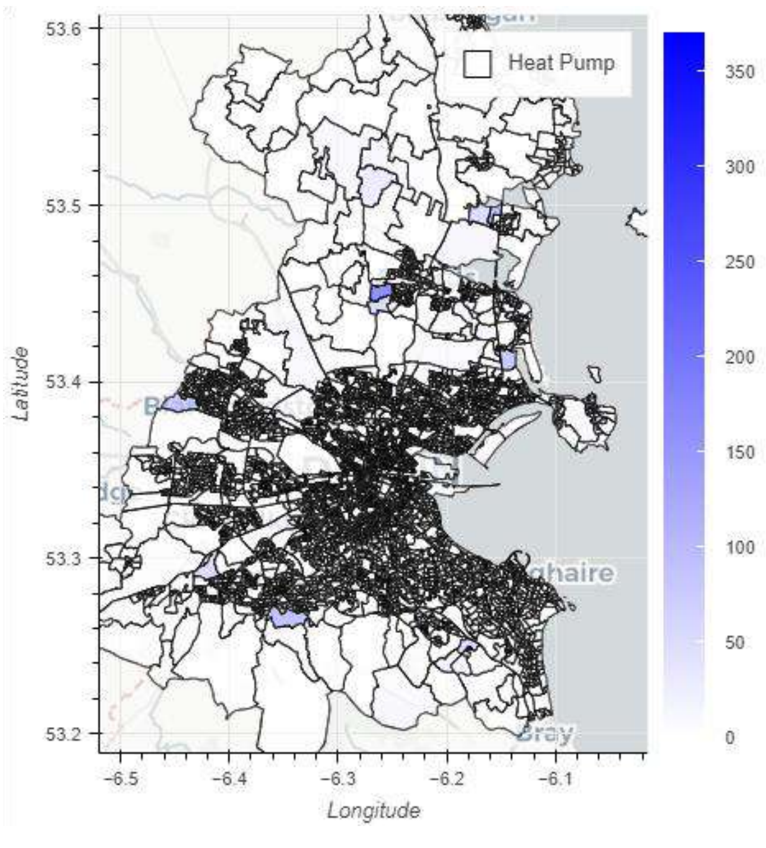

Figure 69: SA Residential Heat Pump Map

Residential space and water heating demands are estimated from the synthetic building stock which, as explained previously, combines the census 2016 (which also gathers the household heating sources by small area) and the BER database (which estimates both space and water heating demands for the different dwelling types by period built in each SA) and is applied to the entire residential building stock.

To generate heat demands, it was assumed that the Dwelling Energy Assessment Procedure (DEAP) model of hot water and space heat demand is indicative of actual usage. In order to determine the emissions associated with heat, the following typical heating system efficiencies were used for each heat source used.

Heat Source	Efficiency
Gas	85%
Oil (Kerosene)	80%
Direct Elec	100%
HP	300%
Wood Pellet Boiler	65%
Stove (soft wood)	65%
Stove (wet wood)	65%
Smokeless Coal	30%
Briquettes	30%
DH	460%

Electricity demands were estimated from the synthetic building stock, which included electricity demands from the BER database; this accounted for space and water heating, pumps, fans and lighting. The smart meter trial[161] data was provided by the Commission for Regulation of Utilities (CRU); this gave information about consumers' electricity usage behaviours and has helped to model demands and different times of the day. This is discussed in further detail in **Appendix D – Electricity Sector Methodology.**

Validating Results

One of the issues with modelling of this nature is the lack of validation capabilities, with the only sources for the residential sector being metered gas data available at postcode level provided by the CSO. Therefore, the gas demand estimated by the residential synthetic building stock model was compared to metered gas demands from the 2016 census to sense check the results obtained from the synthetic building stock. Returning to the sample BER dataset, the portion of buildings that listed "Mains Gas" as the primary fuel type was computed for each postcode, and those values were then applied to the final postcode consumption estimates.

[161] https://github.com/codema-dev/cer-smart-meter-trials-2009-2011

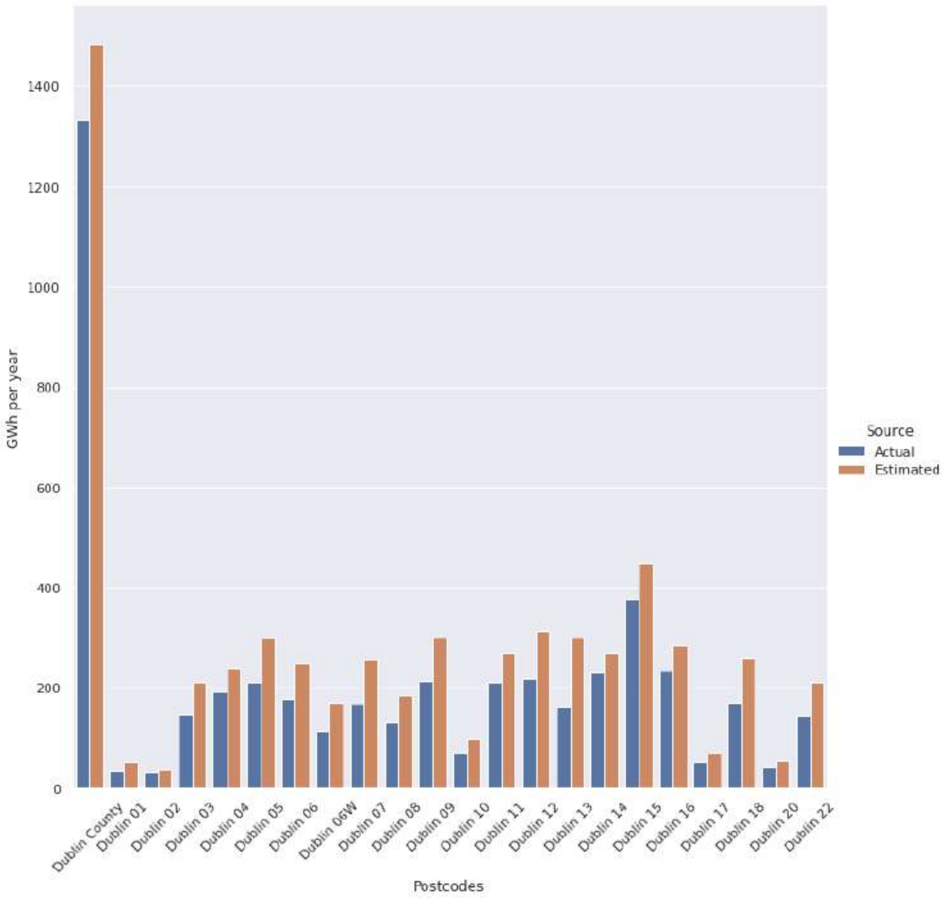

Figure 70: Actual and Estimated Gas Demands

This comparison indicates that the Dwelling Energy Assessment Procedure (DEAP) systematically overestimates demand. It was found that compared to the CSO metered gas consumption, on average the DEAP calculation overestimates consumption by 27%. This might be because DEAP assumes a standard occupancy based on the floor area of the dwelling and also assumes that the dwelling is heated so as to reach a standard set temperature.

A study conducted in the Netherlands by Visscher, H., & Meijer, F. (2016)[162], which compared metered gas consumption with Energy Performance Certificates' (EPCs) theoretical consumption (figure shown on the next page), also came to the conclusion that higher gas consumption estimates are found in theoretical demands, particularly in buildings with a lower energy rating. One of the main findings from this study was that certain poorly insulated households (households with poor EPC ratings) are more likely to consume less than theoretical heat demand due to behavioural changes of occupants to reduce fuel costs (e.g. heating less rooms, accepting lower internal temperatures than assumed in the theoretical estimates but wearing more layers, etc.). This real-world situation is not captured in these models and hence overestimates the demand in less efficient homes. The average BER rating in Dublin is D2, therefore the heat demand reduction between estimated and actual is in line with the range shown for D-rated buildings in the figure shown. With the ultimate dual goal of providing comfortable buildings for all residents and decarbonising, these higher theoretical estimates have been used in the heat analysis. It should be noted that the rebound effect in highly efficient buildings is also included in the heat analysis. The rebound effect is where buildings with high fabric efficiency experience higher than expected demand due in part to the behavioural changes in occupants (i.e. get used to wearing less layers and higher comfort levels) and to differences between the theoretical and actual (as built) buildings.

[162] Visscher, H., & Meijer, F. (2016). Energy regulations for housing and the performance gap. In K. Kähkönen, & M. Keinänen (Eds.), Proceedings of the CIB World Building Congress 2016: Volume I - Creating built environments of new opportunities (pp. 795-805). (Tampere University of Technology. Department of Civil Engineering. Construction Management and Economics. Report). Tampere University of Technology.

Detailed information on the housing stock age and BERs will be discussed in the Findings section below.

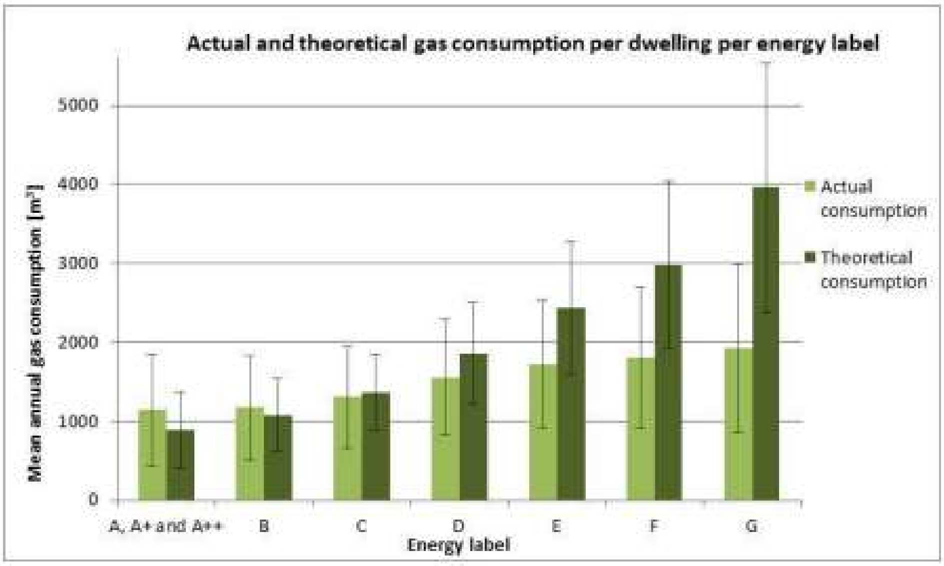

*Figure 71: Actual and Theoretical Gas Consumption per Dwelling **Source:** Visscher et al.*

<u>Findings</u>

From the methodology described above, Codema found that the residential building stock in the Dublin Region is predominantly made up of terraced (36%) and semi-detached (36%) dwellings; these were closely followed by apartments (22%), while the least common housing type in Dublin is detached houses, making up only 6% of the total residential building stock. The housing stock is an ageing and poorly rated building stock, with 78% of the stock having been built prior to the year 2000, which is higher than the national average (71% of the housing stock built prior the year 2000[163]).

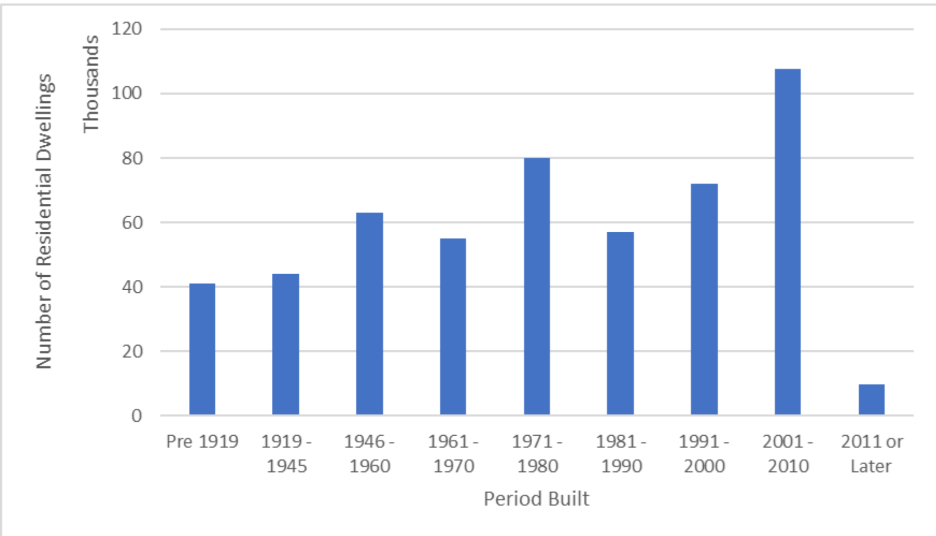

Figure 72: Period Built for the Residential Housing Stock

Since the housing stock is an ageing stock, this affects the energy efficiency of the dwellings and as can be seen in the figure below, it reflects in poor BERs for the Dublin Region. As explained in **Appendix A - Building Energy Model,**

[163] https://data.cso.ie/

Codema generated the synthetic residential building stock for all of Dublin's residential buildings, and thus all residential buildings in Dublin were assigned a BER, which can be seen in the figure below.

In Dublin the most common BER was found to be a D2 rating (17%) for the year 2021. Buildings rated D1 or less made up 58% of the housing stock, whereas A and B rated buildings made up 12% of the stock. A map showing the BERs for each small area can be found on Codema's Tableau website[164].

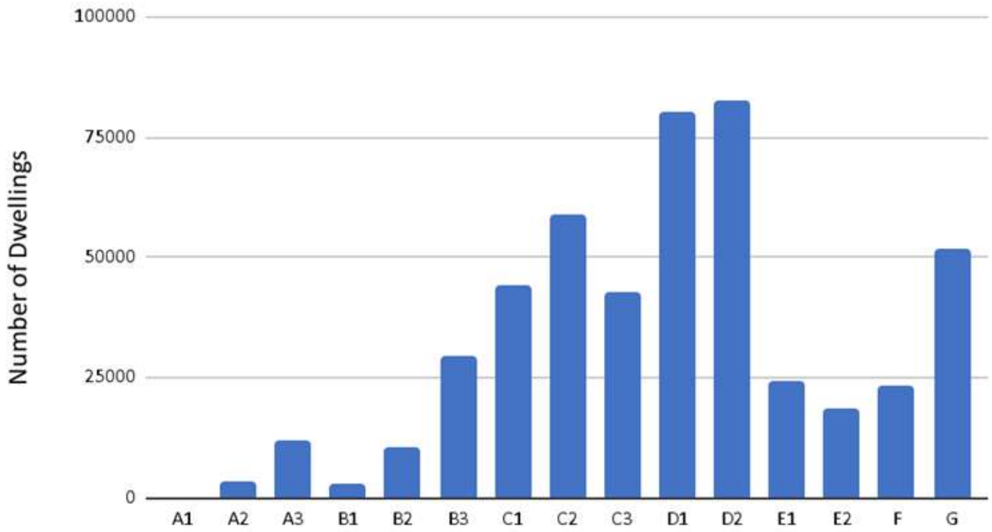

Figure 73: Dublin Region's Residential BERs

[164] https://public.tableau.com/app/profile/oisin.doherty/viz/DublinSmallAreaBER/Sheet1

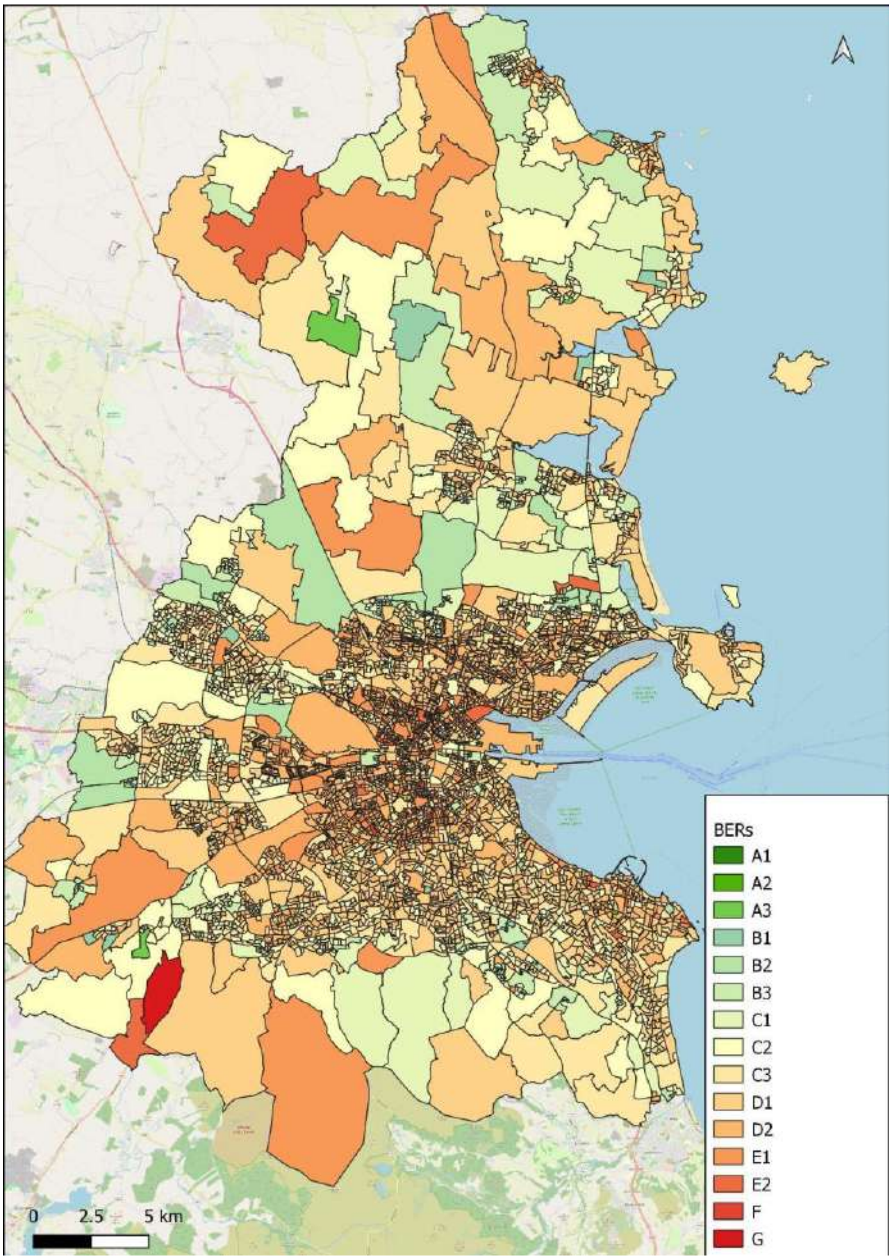

Figure 74: BERs by Small Area

The total energy demand in the residential sector accounted for 10,407 GWh in 2021 in the Dublin Region, of which 80% is heat demand and the remainder (20%) is electricity demand.

The residential sector is heavily reliant on natural gas for space and water heating, whilst electricity in the Dublin Region is mainly used for lighting, pumps and fans, and only 14% of the total heat consumption is sourced from electricity. Emissions from the residential sector account for 1,758.15 $ktCO_2$ for the year 2021.

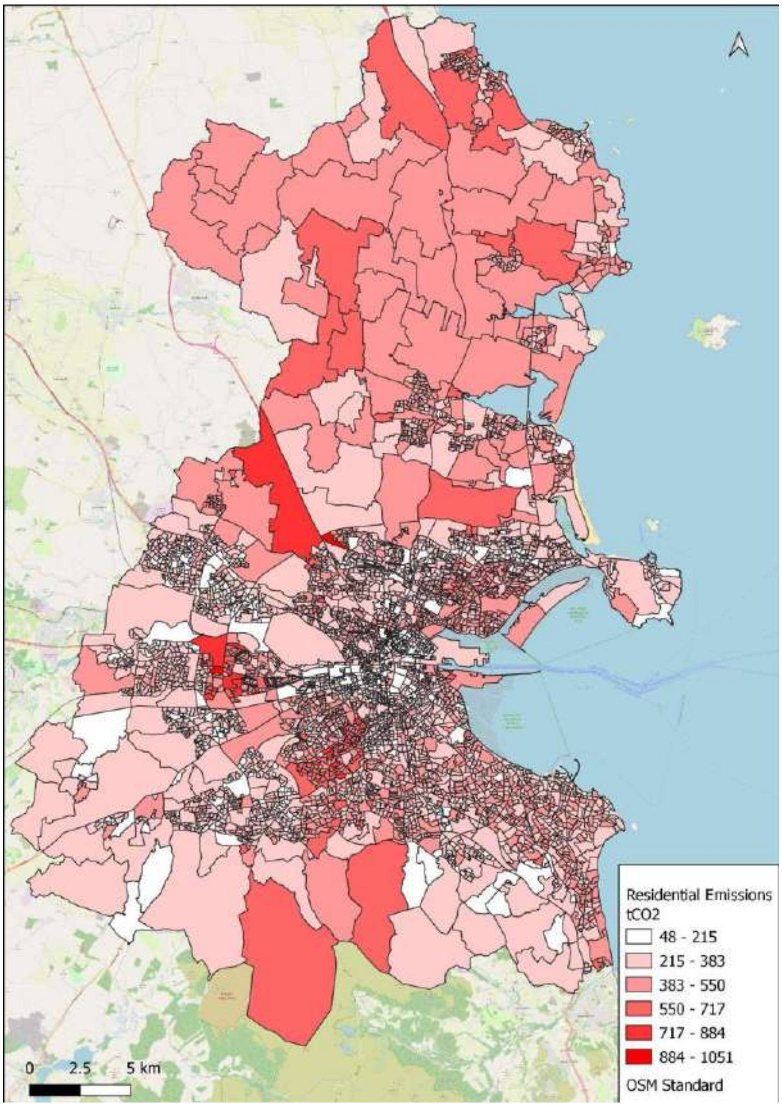

Figure 75: Residential Emissions by Small Area[165]

Non-Domestic

The non-domestic sector includes commercial, public and industrial buildings. The main data source for the non-domestic sector is a detailed list of all rateable commercial buildings, which was provided by the Valuation Office. This data includes a list of all the commercial properties, their location and respective floor areas in the Dublin Region. These properties were also broken down into different categories and types of use. The map on the next page shows the number of non-domestic properties in the Dublin Region and the chart underneath it shows the proportion of the number of buildings to their respective floor areas. By comparing the proportion of floor areas for each commercial category and number of businesses in each category, one can get a better understanding of the different non-domestic buildings in the region. For example, offices make up 47% (12,550 offices) of all non-domestic buildings in Dublin, yet they only take up 19% of the total floor area

[165] https://public.tableau.com/app/profile/oisin.doherty/viz/DublinResiCarbon/Sheet1

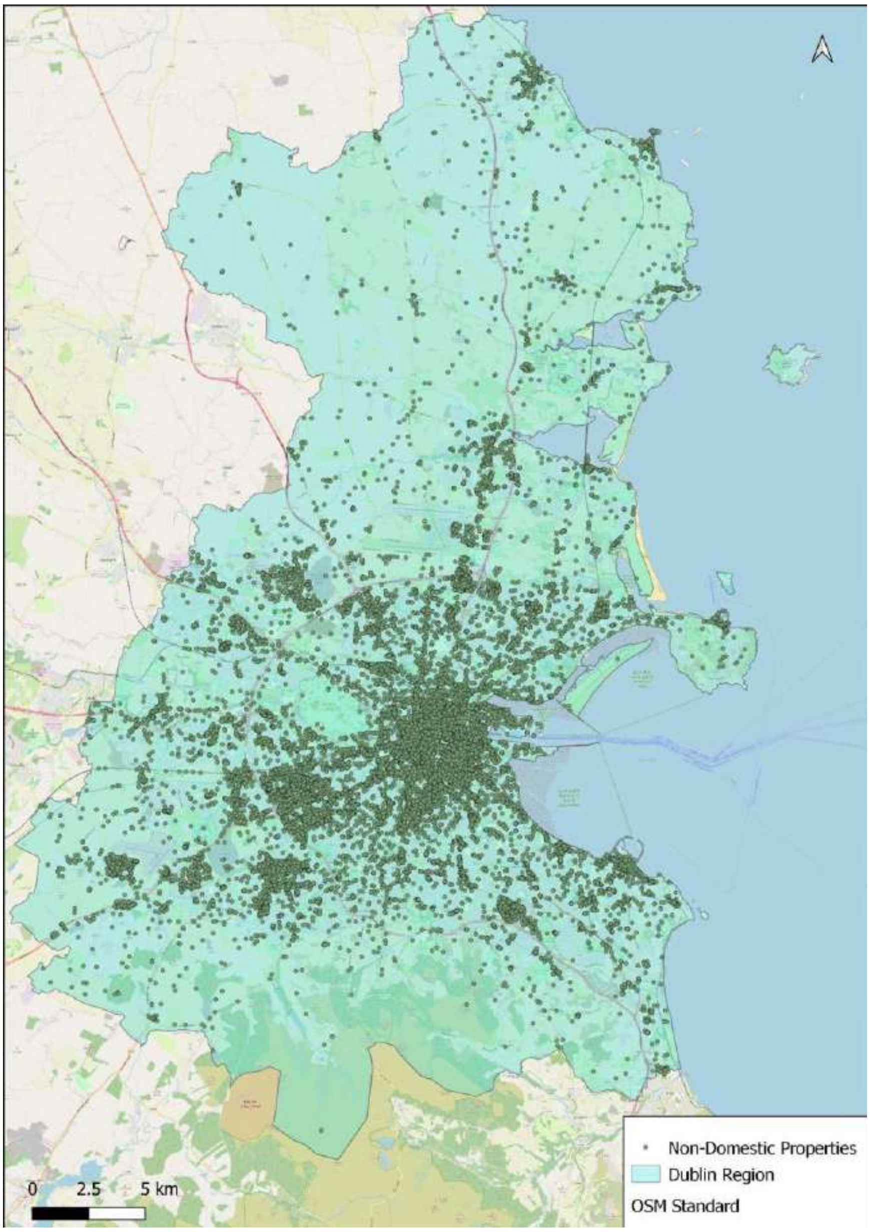

Figure 76: Non-Domestic Properties in Dublin

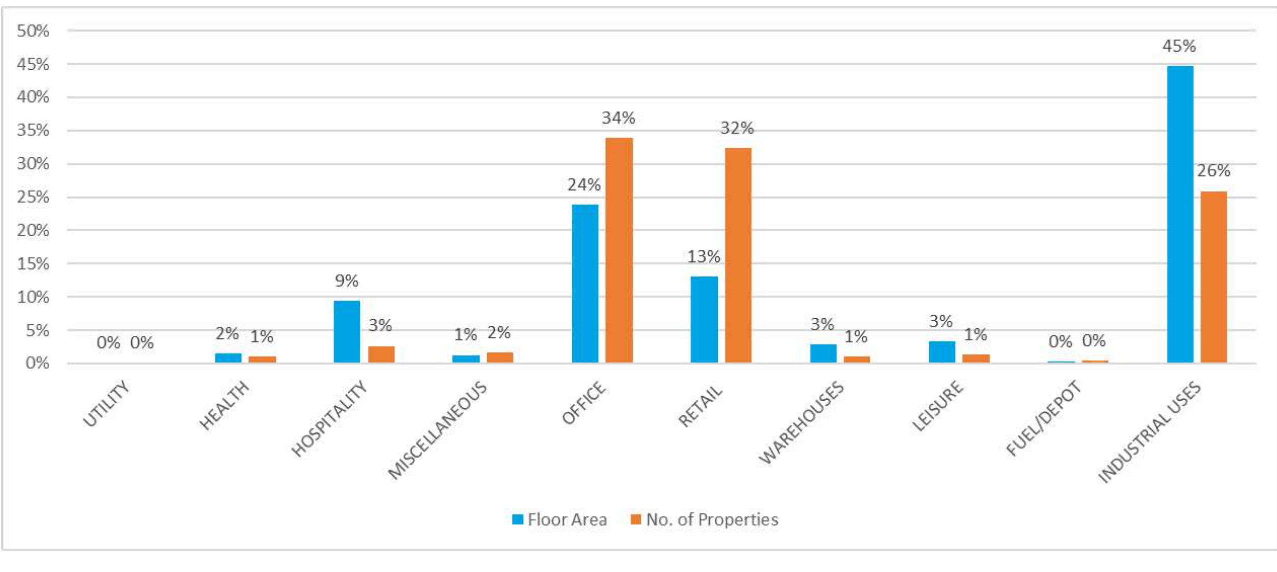

Figure 77: Proportion of Businesses to Floor Areas

This data was used to link all the different non-domestic buildings and to generate the energy demand and emissions from the sector. The detailed methodology and findings for each sector are presented in the sections below.

Public Sector

Data Sources & Methodology

In Ireland, public sector bodies are required to report on their annual energy use and performance to the Sustainable Energy Authority of Ireland (SEAI). This is done through the Monitoring and Reporting system (M&R), which is used to track the public sector's progress towards their energy efficiency and emissions targets compared to the baseline year.

The energy use for the different public sector bodies is reported in terms of building location, use and metered electricity and gas demands. Currently, the public sector M&R gathers all the different public buildings' energy demand in separate electricity and gas demands, so Codema manually linked the buildings' gas and electricity demands.

This process resulted in the generation of metered data for approximately 1,500 public sector buildings for 2018. Once each of the public sector building's metered data was generated, the building locations were matched to the Valuation Office's list of geolocated non-domestic buildings. This processed data can be located on our Codema Github website.[166]

Findings

The total metered energy demand for the public sector in 2018 was 1.23 TWh, of which 45% (559 GWh) came from electricity and 55% (676 GWh) from gas consumption.

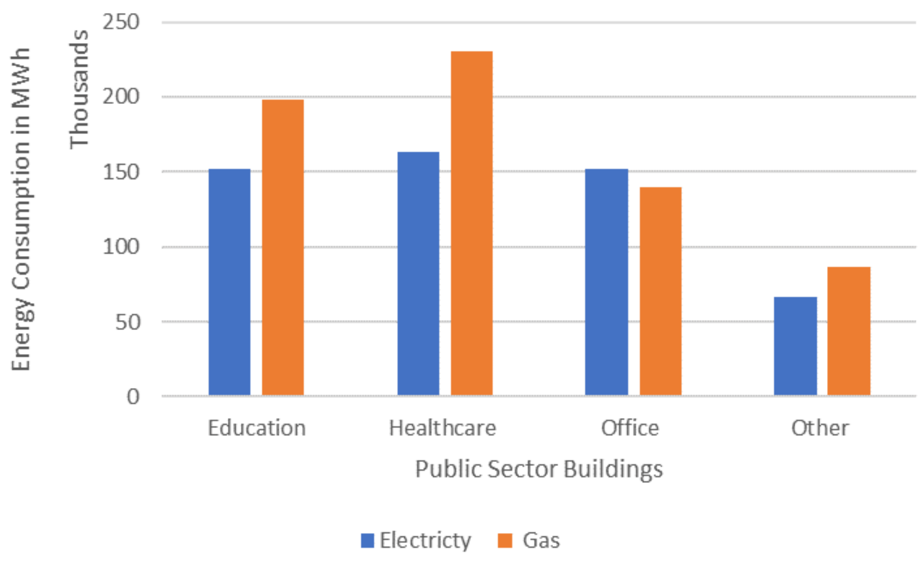

Figure 78: Public Buildings' Gas and Electricity Energy Demand

This resulted in a total of 303,276 tCO_2 emitted, of which healthcare buildings emitted the most CO_2 of all public sector buildings (100,081 tCO_2), followed by education buildings at 90,982 tCO_2. Offices account for 72,786 tCO_2 of total public sector emissions and other buildings (which include buildings such as post offices, public theatres and national galleries, etc.) amounted to 39,425 tCO_2.

[166] https://codema-dev.github.io/data/public-sector-electricity-and-gas-demand/

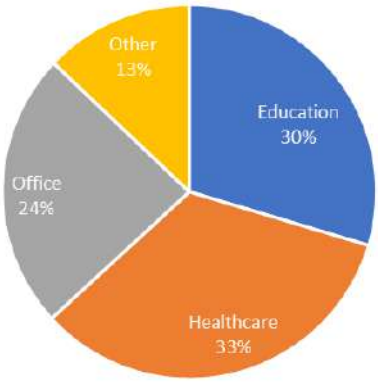

Figure 79: Public Buildings' Emissions Breakdown by Sector

Commercial

The commercial building sector is the most difficult sector to estimate building energy demand due to the lack of data available to develop a more robust methodology. The lack of data in this sector is not specific to Ireland, and provides a challenge for which all EU member states will need to overcome. Work on analysing energy use in the sector is ongoing and significant advances in the collection and analysis of data have been made in recent years to improve the understanding of the profile of the commercial sector, energy use and energy saving opportunities.

Data Sources & Methodology

The methodology used for the calculation of the commercial baseline includes two main data sources - data from the Valuation Office and energy consumption benchmarks from the Chartered Institution of Building Services Engineers (CIBSE). Currently, there is no energy data available for commercial properties, as there is no formal energy reporting required. Therefore, in order to assign energy use to each property, Codema used energy benchmarks from the UK CIBSE Guide F: Energy Efficiency and TM46 (CIBSE, 2012). These sources provide typical energy usage per square metre of floor area for different business categories, amalgamated from numerous UK surveys. The energy benchmarks were weather adjusted depending on the Irish heating degree day for the Dublin Region, before being applied to the commercial building stock. Codema matched the property uses provided by the Valuation Office with the building descriptions given in the CIBSE guides. The floor areas listed by the Valuation Office were based on the different business requirements. This can be found in the Valuation Office's Code of Measuring Practice (Valuation Office Ireland, 2009). If the measured floor area from the Valuation Office did not match that in the CIBSE guides (gross floor area to net floor area), then a conversion factor was applied. Codema then applied energy figures to all the commercial properties, depending on their use. There were over 230 different property types listed in Dublin.

The CIBSE energy figures are only split into either fossil fuels or electricity. Therefore, due to a lack of data at a local level, the national breakdown of fossil fuels and electricity for energy use in the industrial sector was used instead. However, this presents a limitation, as it is not an accurate representation of fuel use in the commercial sector in the Dublin region.

Other avenues were explored, such as establishing benchmarks based on commercial BERs and public sector M&R data; however, these efforts were ultimately abandoned due to data quality issues. The commercial BERs do not contain metered data but rather theoretical demands and cannot be geolocated. Creating floor area energy benchmarks on theoretical demands that cannot be linked back to the valuation office dataset was not deemed worthwhile.

Findings

The chart below shows the share of energy demand for electricity and fossil fuels for each of the commercial categories identified. It can be seen that fossil fuels by far make up most of the energy consumption, the total energy demand for this sector was 4,114.88 GWh, of which 1349.26 GWh came from electricity and 2765.62 GWh from gas consumption.

Of all the commercial categories, the health sector was found to have the highest reliance on fossil fuels (82% of the energy demand came from fossil fuels and 18% from electricity), whereas retail properties are heavily reliant on electricity (69% of the energy demand was met by electricity and 31% from fossil fuels).

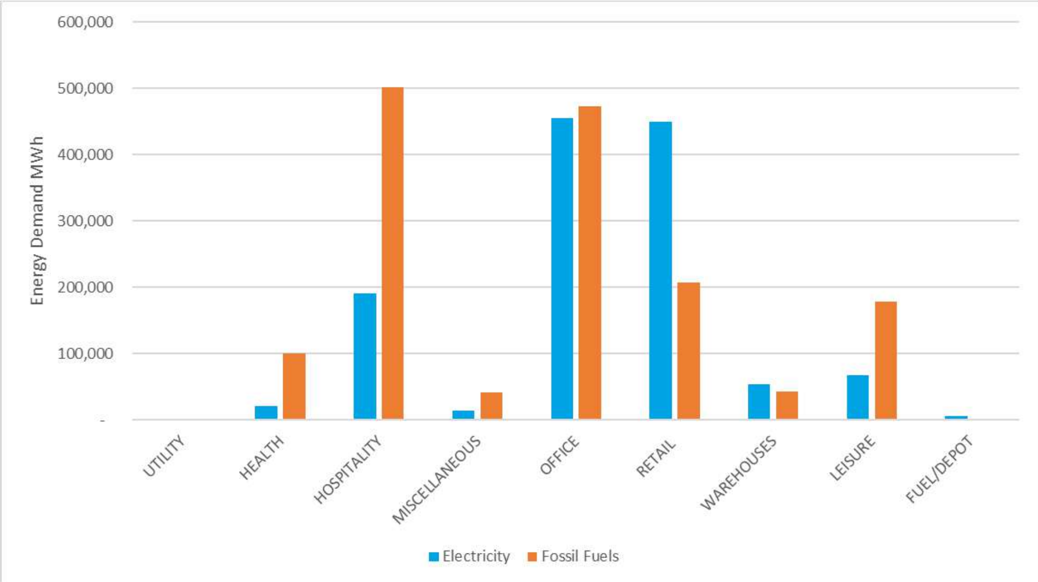

Figure 80: Energy Demand for Each Commercial Category

These commercial categories were then further broken down into building uses (as can be seen in the figure below). Commercial buildings and services resulted in a total of 1,016 $ktCO_2$ of emissions emitted. Of which, storage facilities (which include warehouse and bulk stores from the retail, office and leisure categories) and general offices each make up 26% of total emissions in the commercial sector.

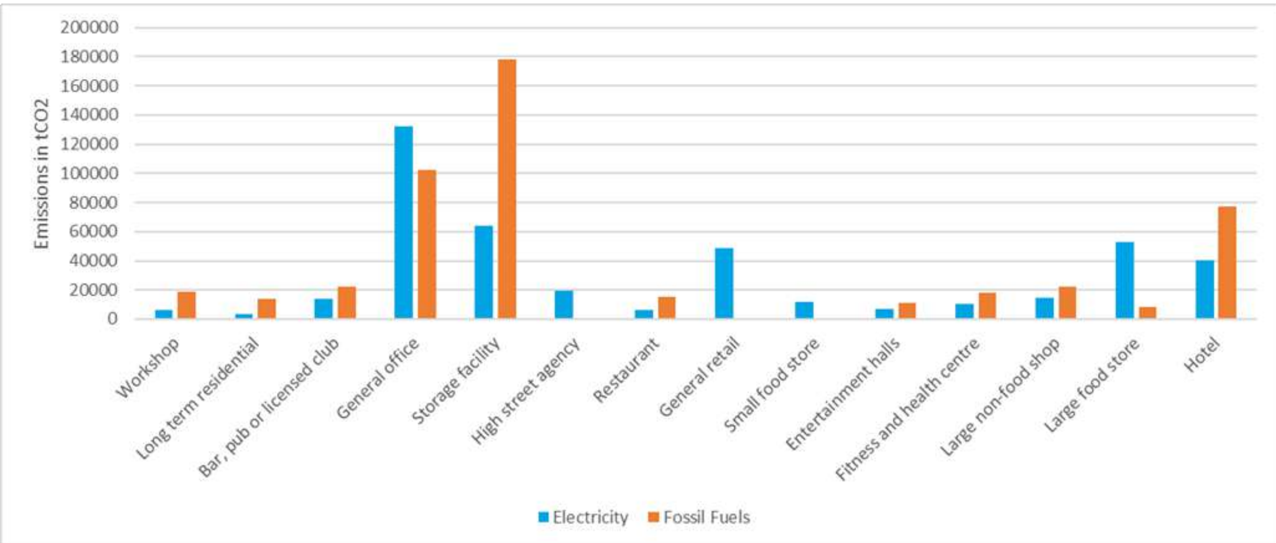

Figure 81: Commercial Use Emissions Split into Electricity and Fossil Fuel Use

Industrial

Data Sources & Methodology

Industrial energy demands were estimated by combining two approaches. When industrial site-specific annual energy demand data was available on the EPA website[167] through Annual Environmental Reports (AER), these were made use of. The AERs are used to provide a concise summary of licensees' environmental performance; some of the information

[167] https://www.epa.ie/our-services/compliance--enforcement/industry-and-waste-management/compliance-and-performance-reporting-by-licensees/annual-environmental-report-aer/

captured in the AER include the companies' environmental objectives and targets achieved, goals to maintain compliance and summary results from emissions monitoring, which includes energy demands (in kWh) broken down by fuel used. When this information is unavailable, CIBSE Guide F floor area energy benchmarks were applied to Valuation Office floor areas on corresponding building use categories. Guide F provides energy benchmarks for space heat, building energy and process energy. Process energy was split into high and low temperature heat by assuming that 86% of process energy is high temperature (i.e. greater than 100°C and not suitable for district heating or heat pumps) and the remainder low (for all site types other than Storage/Cold Storage, which is assumed to be 35%). To avoid double counting, it was necessary to geocode the EPA industrial sites and manually match them with their corresponding valuation site IDs.

Industrial emissions captured by the AER reports were not included in the final energy demand and emissions, as most of these big industries can be categorised as ETS, thus only the remaining industrial energy demands have been accounted for.

It should be noted that the electricity demand from data centres is discussed in detail in **Appendix D - Electricity Sector Methodology.**

Findings

The total energy demand for the industrial sites as reported to the EPA in 2018 was 4.36 TWh, of which 23% of energy demand was met by electricity and 77% by gas consumption. This resulted in a total of 1,248 ktCO_2 of emissions emitted. The figure below shows the emissions from industrial businesses broken down into electricity and fossil fuels. It can be seen that this industry relies heavily on fossil fuels, as they make up most of the emissions.

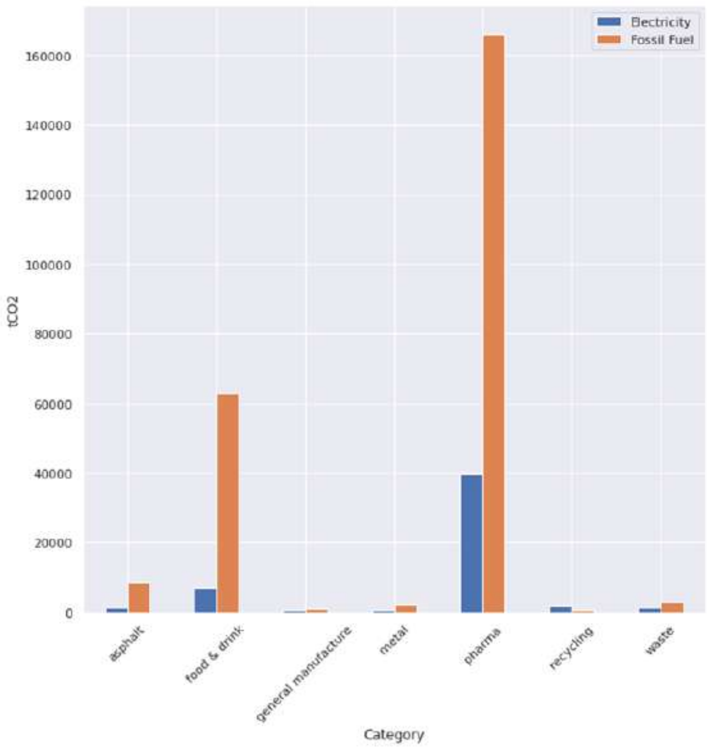

Figure 82: Industrial Emissions

The remaining energy demand (i.e. the industrial sites not accounted for by the AER) for this sector in 2018 was 0.72 TWh, of which 0.30 TWh from electricity and 0.42 TWh from gas consumption. This resulted in a total of 180,193 tCO_2 of emissions emitted.

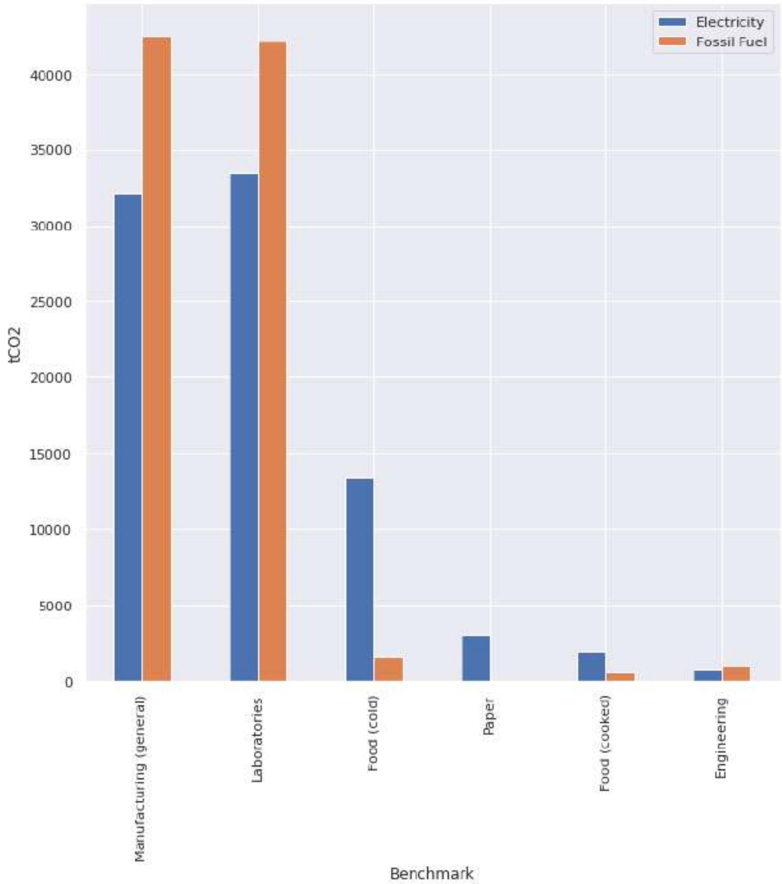

Figure 83: Industrial Emissions (Using benchmarks)

Total Non-Domestic Energy Use and Emissions

The total energy demand from non-domestic buildings is 6,300 GWh for commercial buildings and services (65%), the public sector (20%) and industrial uses (15%) (this does not account for ETS emissions). The figure on the next page shows the total energy demand in each SA. It can be noted that highest emissions pertain to areas within the region that have a high number of commercial properties and energy intensive businesses.

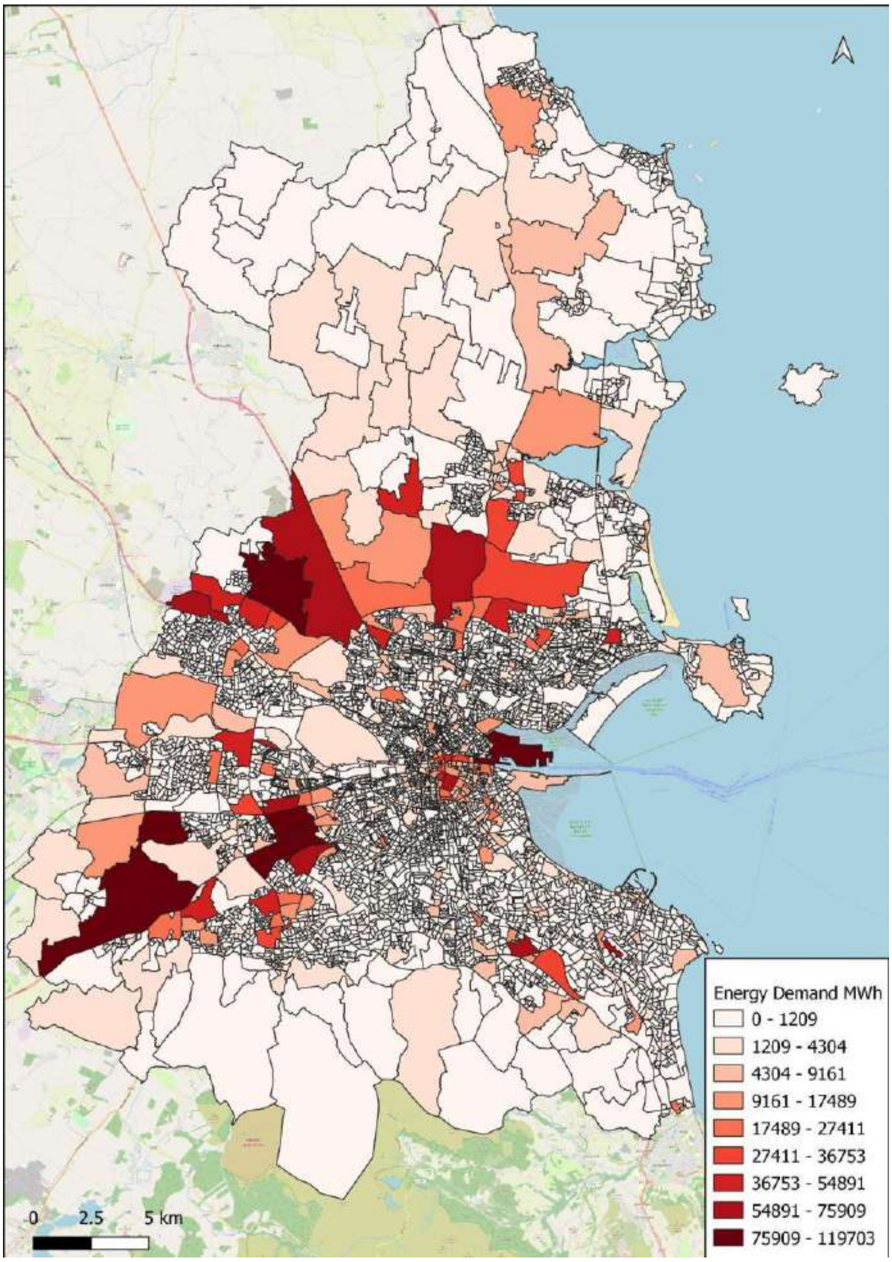

Figure 84: Commercial Energy Demand

Total emissions for the non-residential sector make up 1,589ktCO_2, of which 55% are emissions from fossil fuels and the remainder (45%) from electricity.

Total Energy Demand and Emissions from the Building Sector

Total energy demand from buildings and services accounted for 58% of total energy consumption in the Dublin Region (16,706 MWh),[168] 31% of the demand was met by electricity and the rest, 69%, by fossil fuels (predominantly natural gas). The SA emissions from buildings can be found in the figure on the next page. It can be noted that the highest emissions pertain to areas within the region that have a high number of commercial properties and energy intensive businesses. Buildings and services accounted for 3,347.6 ktCO_2 (approximately 56% of total emissions); this might be attributed to the high building density in the region and an ageing housing stock, with 78% of the stock in Dublin having been built prior to the year 2000.

[168] This does not include data centres

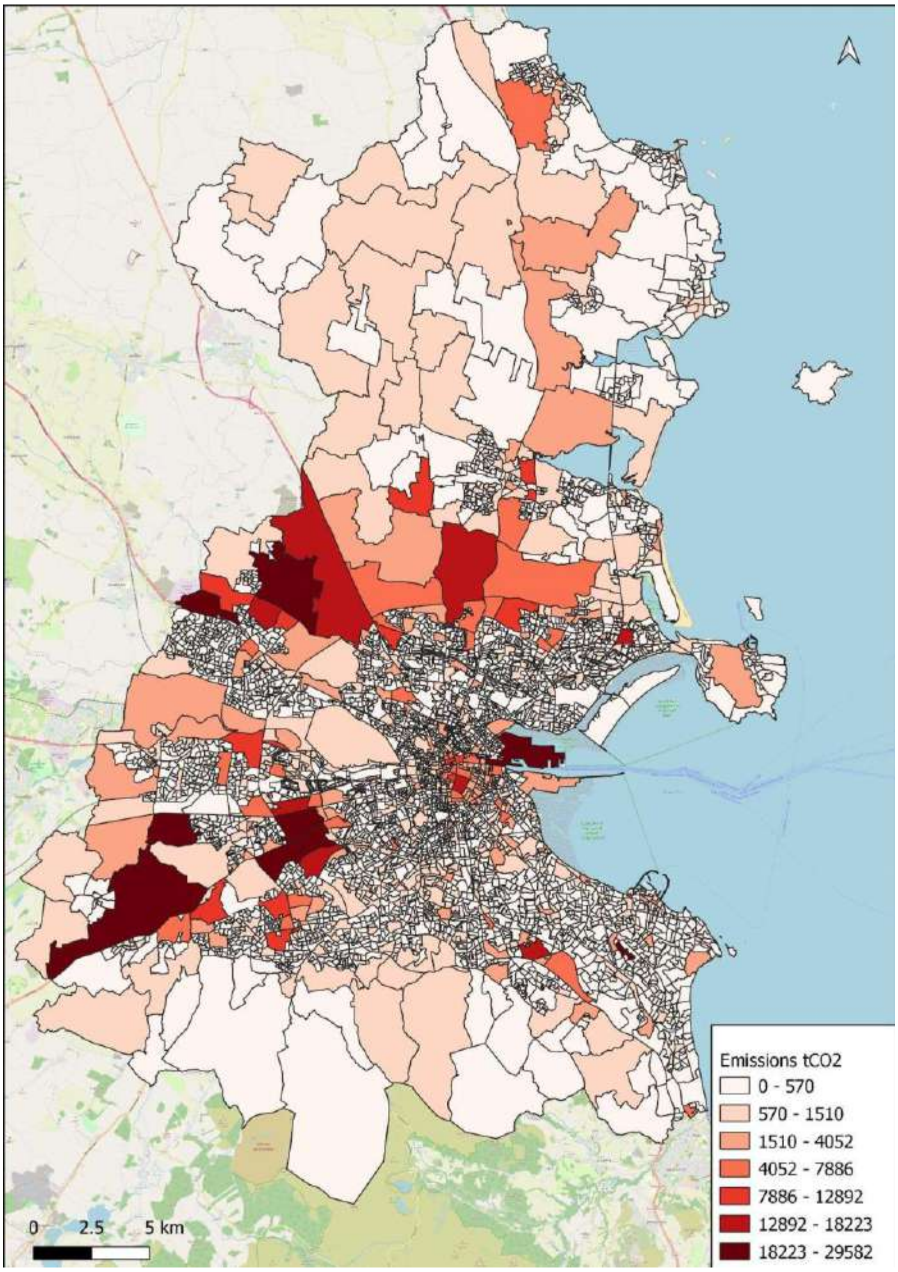

Figure 85: Building Emissions by Small Area

Building Energy Efficiency Upgrades

To meet 2030 and 2050 decarbonisation targets, the building stock will need to be highly energy efficient. This would mean that all new buildings are built to nZEB standard (as described in the Building Regulations Section of this Appendix) and that the majority of existing buildings undergo energy efficiency upgrades or retrofits. Ireland's Long Term Renovation Strategy[169] suggests that by 2050, it is expected that more than 1.5 million buildings in Ireland will need to be retrofitted.

Ireland's Climate Action Plan, which sets out a roadmap to 2030 in line with the 2050 decarbonisation target, includes a number of actions for energy upgrades to 2030, some of which are listed below:

Residential Sector – Retrofitting 500,000 homes to a B2 BER or cost optimal equivalent or carbon equivalent

[169] https://www.gov.ie/en/publication/a4d69-long-term-renovation-strategy/

- Local Authorities upgrading their housing stock under Phase 2 of the social housing retrofit programme to bring dwellings to a BER level of B2 or cost optimal equivalent
- Installing 400,000 heat pumps in existing buildings

Commercial Sector - At least one third of total commercial properties to be upgraded to a B NDBER

- Public buildings need to meet a reduction of 50% in emissions

Existing Building Renovation Regulations

For existing buildings due to undergo major works including renovations (where more than 25% of the surface area of the building envelope undergoes renovation), material alterations or change of use, it is required that the building be brought up to cost-optimal levels (in so far as this is technically, functionally and economically feasible), which typically corresponds to the BER rating of 'B'. Cost-optimal levels are defined in the building regulations as:

U-value requirements for different major works:

- Extensions need to comply with U-values set out in Table 1 of TGD L (and summarised above)
- Buildings undergoing Material Alterations need to comply with U-values set out in Table 10 of TGD L
- Buildings that are undergoing a Material Change of Use need to comply with U-values set out for retained elements set out in Table 11 of TGD L

Cost-optimal improvements for buildings undergoing major renovations include improvements which deliver a whole building primary energy performance level (calculated using NEAP) in accordance with levels set out in Table 13 of TGD L or which include the following:

- Upgrade Heating Systems - boilers that are more than 15 years old and with efficiency less than that shown in Table 2 of TGD L. Direct electrical heating system to achieve levels shown in Table 5 of TGD L
- Upgrade Cooling and Ventilation Systems that are more than 15 years old and have a SEER that is less than Eco-design regulations (paragraph 1.4.3.11) or SFP greater than shown in Table 12 of TGD L
- Upgrade Lighting that is more than 15 years old or have an average lamp efficacy of less than 40 lamp-lumens per circuit-watt that serves greater than 100m^2 (see guidance in section 2.2.7 of TGD L)

Major Renovations in Residential Buildings

For existing dwellings due to undergo major renovations (where more than 25% of the surface area of the building envelope undergoes renovation), it is required that the building be brought up to cost-optimal levels, defined as 125kWh/m^2 per year when calculated in DEAP. This corresponds to a BER Rating of 'B2'.

Major renovations to dwellings will require compliance based on factors set out in Table 7 of TGD L and are summarised below.

- Upgrade insulation at ceiling/roof level where U-values exceed limits set in Table 5 of TGD L
- Upgrade heating systems (including controls) that are more than 15 years old and in the case of boilers are less than 86% efficient and in the case of electric storage heating, when heat retention is 45% or above according to EN60531
- In the case of major renovation brought about due to new extension, wall insulation shall be upgraded where U-value limits in Table 5 of TGD L are exceeded

Elements that are included in the surface area calculation for major renovations are as follows:

- External wall renovations, including external insulation of heat-loss walls, replacement or upgrading of external wall structure and internal lining of the surface of heat-loss walls. Note that painting, re-plastering, rendering, re-tiling/re-slating, cavity wall insulation and ceiling insulation are not considered major renovation works.
- Replacement of windows
- Replacement of roof structure
- Replacement of floors
- Extensions which affect more than 25% of the surface area of the existing dwelling

Major Renovations in Non-Domestic Buildings

Major renovations are defined as renovation where more than 25% of the surface area of the building envelope undergoes renovation. This includes extensions which affect 25% of the building envelope. Elements which are included in the surface area calculation for major renovations are as follows:

- Cladding the external surface of the element
- Drylining the internal surface
- Replacing windows
- Stripping down the element (exposing the basic structural components e.g. blockwork, timber/steel frame, joists, rafters etc.) and then rebuilding to achieve the necessary performance requirements

Major alterations are understood to be alterations (other than a repair or renewal) where the work, or any part of the work, carried out by itself would be subject to the requirements of the building regulations.

Constraints and Barriers to Retrofits

Barriers to building retrofits can be attributed to a number of different issues, most of these barriers are common to both residential and non-residential buildings. From Codema's Zero Together Survey,[170] which ran during September and October 2021, respondents highlighted barriers such as cost, poor infrastructure and lack of information and awareness as barriers to those living in Dublin to take direct action. The Long Term Renovation Strategy also highlights that the key barriers around retrofits can be described as:

- Accessibility – making it possible and easy for decision makers to retrofit their buildings
- Affordability – retrofit costs can be quite expensive especially to meet specific building regulation standards
- Appetite – there is a need to make business and homeowners aware of the benefits of energy efficiency upgrades.

Cost

One of the key constraints to retrofits is cost. Codema's combined energy efficiency and deprivation map below shows the measure of deprivation for small areas in the Dublin Region, with areas of high affluence shown as green and least affluent areas in red[171] (an energy poverty map, mapping residential dwellings that have a D1 BER or lower and a high unemployment rate and deprivation index, can be found in **Appendix F Socio-Economic Impacts**). The deprivation index helps policy makers and researchers to identify unprivileged areas and has demonstrated strong correlations with a range of health and social outcome measures across many countries.

[170] http://www.codema.ie/media/news/survey-national-government-most-responsible-for-tackling-dublins-fossil-fue/

[171] Deprivation Index > 30 - Extremely Affluent, 20 to 30 - Very Affluent, 10 to 20 - Affluent, 0 to 10 - Marginally Above Average, -10 to 0 - Marginally Below Average, -20 to -10 Disadvantaged, -30 to -20 - Very Disadvantaged , < -30 Extremely Disadvantaged

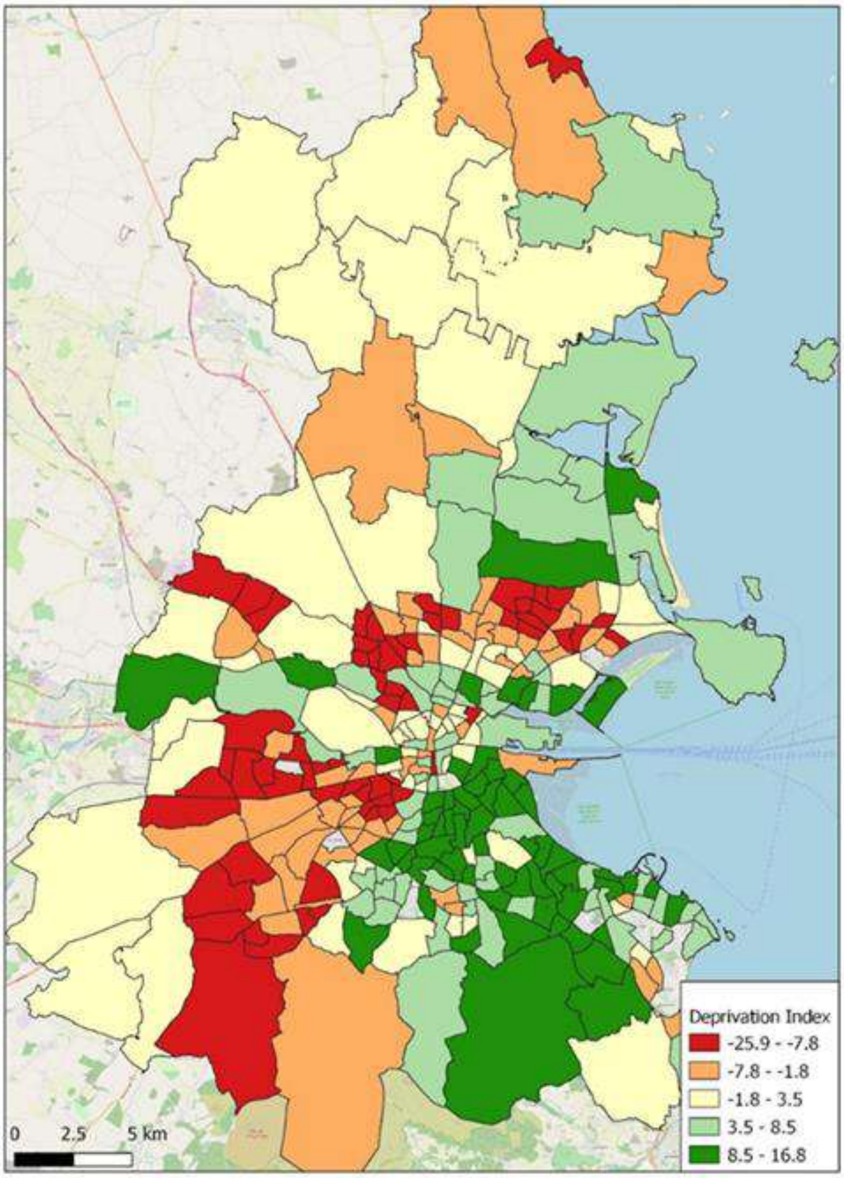

Figure 86: Deprivation Index Map for the Dublin Region. Source: CSO 2016 Deprivation Index

Considering that the average BER in Dublin for residential dwellings is a D2 and that the commercial sector is also an ageing and inefficient stock, the cost to retrofit these buildings will be quite high. This is even more so when specific heating technologies (such as heat pumps) would require a sufficiently energy efficient building.

<u>Consumer Behaviour and Consumption Practices</u>

Although progress has been made in accelerating energy renovation in Ireland, it is widely accepted that there is a large gap between the actual and required level of investment. Cost and long payback periods for retrofits also make it difficult for customer buy-in. This can be further exacerbated by consumer behaviour and consumption practices. In general, higher rated dwellings (both new and buildings that have been retrofitted to high BER) tend to use more energy than predicted as occupants become used to the higher comfort levels, while poorly rated dwellings tend to use less energy than predicted by choosing to leave zones of their home unheated.

In a paper on the rebound effect in residential dwellings, Aydin et al[172] compared theoretical consumption (based on that expected from the Energy Performance Certificate) to actual consumption (based on metered gas consumption) for 710,000 buildings in the Netherlands. It was found that as energy efficiency gains change the perceived cost of energy services generate shifts in consumption patterns in what is referred to as the Rebound Effect. In simple terms the Rebound Effect is the percentage of the theoretical savings that are not realised in reality. The results of this study show a rebound effect of 26.7 % among homeowners, and 41.3 % among tenants. They also show the rebound effects are greatest among the lower income-wealth groups, and among households that tend to use more gas than average. An average of these figures has been applied to the calculated energy savings to provide a more realistic estimate of post retrofit demand.

<u>Home and Business Tenure</u>

Home and business tenure is an important consideration for building energy upgrades. People living or have a business in rented accommodations are less likely to take on any upgrades to their property, whereas owner-occupied buildings are more likely to be retrofitted as the owner occupier will reap the benefits in the reduction of consumed energy costs. This often means that for rented accommodation/business properties, building owners would have very little incentive to invest in costly measures to improve energy efficiency as they do not directly benefit from them. Introducing minimum energy performance standards for rented buildings might be a way to increase the rate of retrofits in these buildings.

This map of Housing Percentage Ownership was created using the open-access Small-Area Population Statistics (SAPS) 2016 data provided by the CSO. Ownership was calculated by dividing the total number of dwellings owned with a mortgage (T6_3_OMLH":"Owned with mortgage or loan"), together with the dwellings owned outright (T6_3_OOH":"Owned Outright") by the total number of dwellings ("T6_3_TH":"Total"). The colour ramp represents percentage ownership of the housing stock where red and green indicate a higher and lower ownership, respectively.

[172] Aydin, E., Brounen, D. and Kok, N., 2013. *The Rebound Effect in Residential Heating*. https://www.tilburguniversity.edu/sites/tiu/files/download/The%20Rebound%20Effect_EA300813.pdf

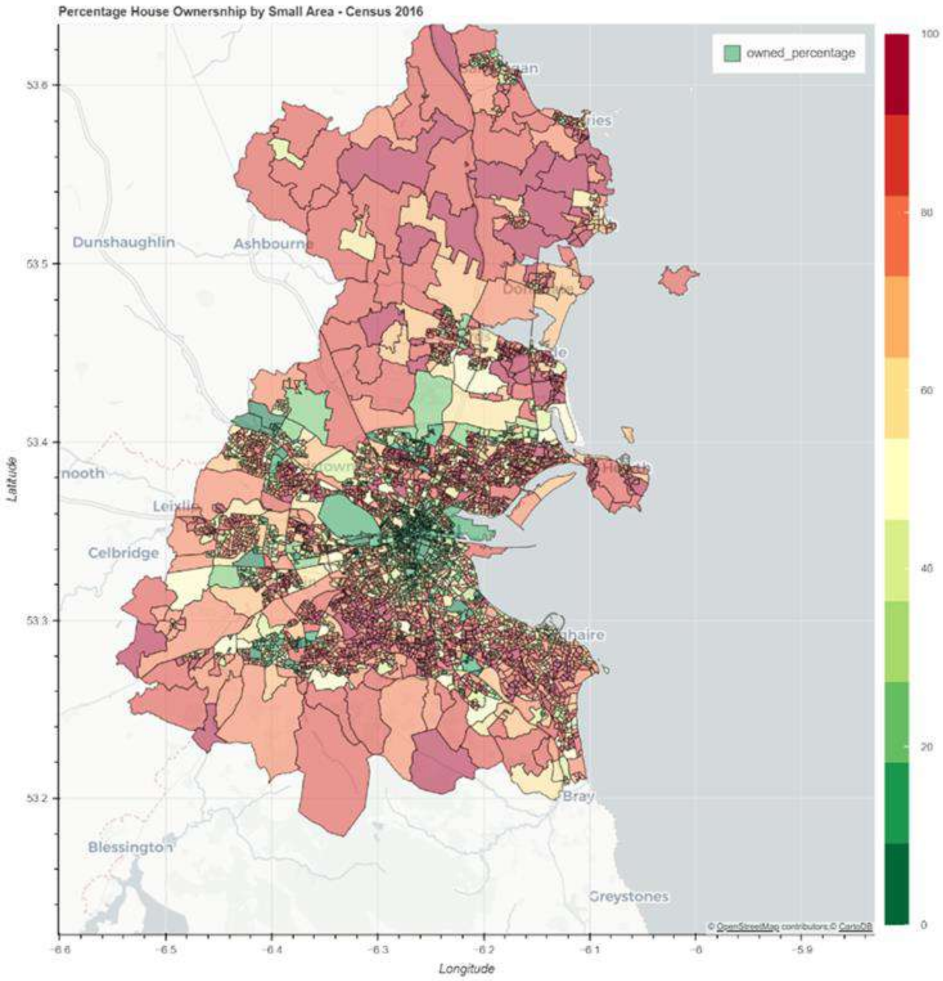

Figure 87: Home Ownership Percentages in Dublin by Small Area[173]. Source : Census 2016

The figure above, shows the home ownership percentages in the Dublin Region. It can be seen that the lowest level of home ownership can be found in the inner city area; these areas overlap with areas that have a high number of apartments. For example, 52% of all residential buildings in Dublin 1, 2, 7 and 8 are apartments; these same areas also have poor BERs, with 68% of the residential stock with a D1 BER or worse. Therefore, these buildings (inner city apartments) will be some of the hardest to retrofit.

<u>Technological Constraints</u>

One of the main constraints to the adoption of individual building-level heat pumps is the requirement to have a sufficiently energy efficient building that allows the heat pump to supply adequate heat (enough to keep the building at a comfortable temperature) without detrimental effects to the HPs efficiency.

[173] https://codema-dev.github.io/map/housing-ownership/

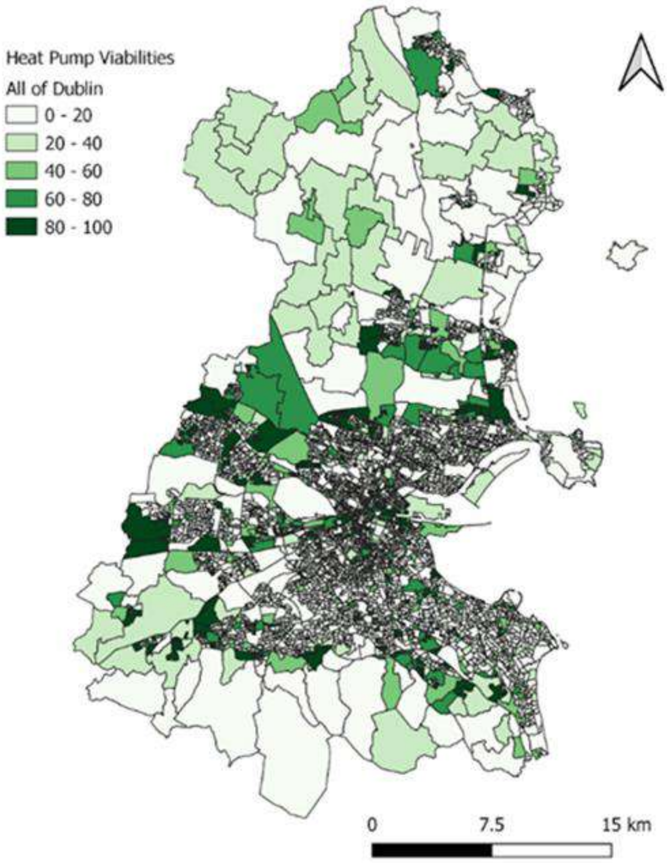

Figure 88: Current Heat Pump Viability in Dublin

The metric used to assess a building's suitability for heat pumps is known as the Heat Loss Index (HLI). In order for a residential dwelling to be deemed suitable, it requires a HLI of 2 W/K m^2 floor area or less. The HLI can be defined as the total heat loss (fabric and ventilation losses). Where the HLI is between 2 and 2.3 W/K m^2, in some cases it may not be feasible to upgrade the home further, in this case a HLI of 2.3 can be accepted once the following criteria[174] are satisfied:

- Maximum exposed wall U-value 0.37 W/m^2K
- Maximum roof U-value 0.16 W/m2K or 0.25 W/m^2K where not accessible (e.g. flat roof or rafters)
- Maximum Window U value 2.8 W/m^2K (and double glazed)
- Maximum Adjusted Infiltration Rate of 0.5 ac/h

Heat pumps for the building sector are discussed in further detail in **Appendix C - Heat Sector Methodology.**

The map of heat pump viability (shown in Figure 88 above) was created using Codema's synthetic building stock; it maps out the HLI indicators that are less than two, to create a map of heat pump viability in each small area.

Protected Structures

Heritage buildings are protected under the National Monuments Acts[175], protected structures and proposed protected structures are exempt from the requirements to have a BER.

[174] https://www.seai.ie/publications/Technical_Advisor_Role.pdf
[175] https://www.irishstatutebook.ie/eli/2004/act/22/enacted/en/print

'A protected structure is a structure that a planning authority considers to be of special interest from an architectural, historical, archaeological, artistic, cultural, scientific, social or technical point of view. '[176]

Owners of protected structures are legally obliged to prevent it from becoming endangered. Planning permission is needed to carry out work on a protected structure that could materially affect its character. This means that many types of work, which in another building would be considered exempted development, may not be exempted where the building is a protected structure. Depending on the nature of the structure and the features of interest, even work such as painting the interior or replacing windows could affect its character and require planning permission.

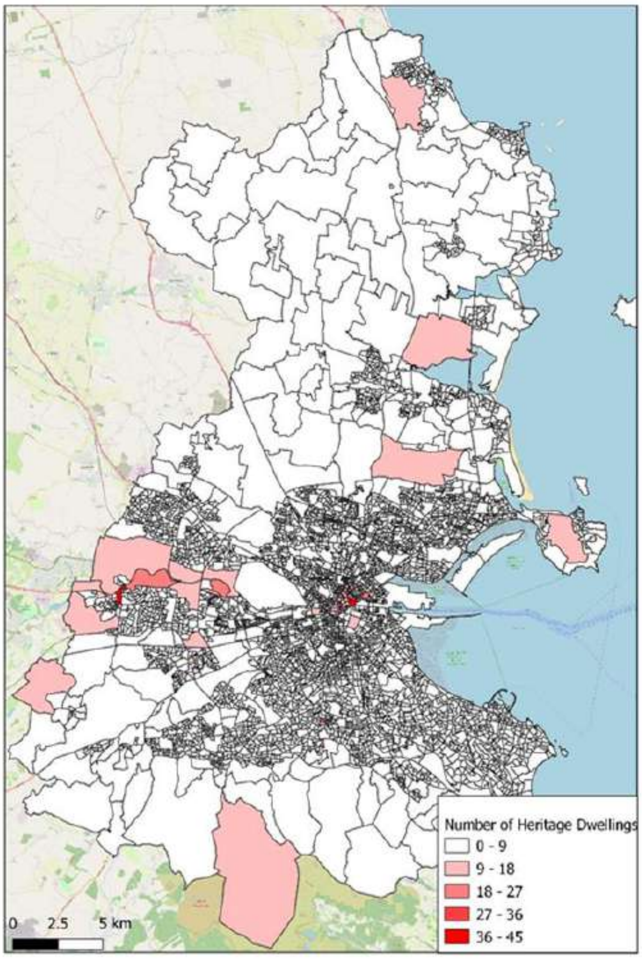

Figure 89: Number of Heritage Dwellings

[176] https://www.sdcc.ie/en/services/planning/heritage-and-conservation/protected-structures/

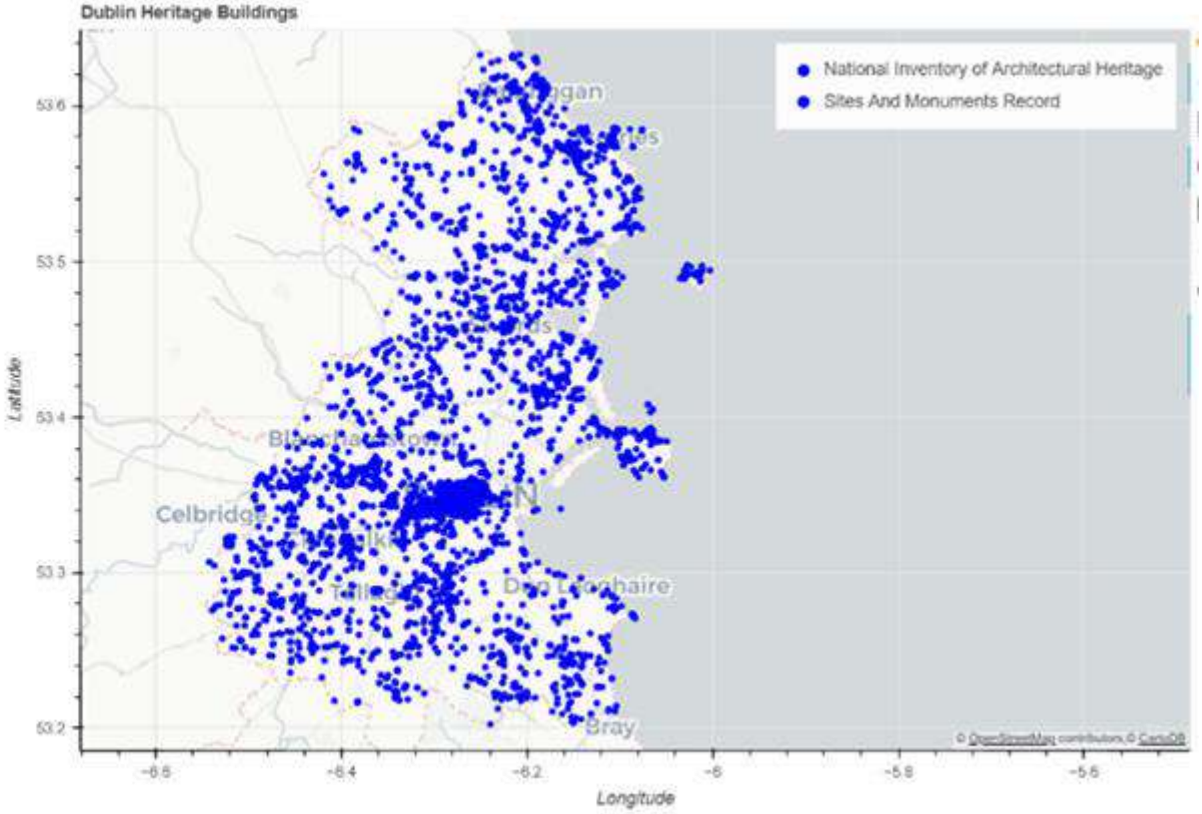

Figure 90: Dublin Heritage Buildings[177]

The map above shows all the heritage buildings that can be found in Dublin. The map was created using data from the National Inventory of Architectural Heritage and Sites and Monuments Record. In the Dublin Region, a total of 420 heritage buildings were identified; for the purpose of this project these buildings were not considered suitable for energy efficiency upgrade works.

Building Renovation Passports

To meet the scale of deep retrofit needed for the building sector, a big increase in energy efficiency measures is needed. Overcoming the current shortfall in action and investment requires addressing key barriers, including low levels of awareness among homeowners and occupiers; a lack of information about appropriate retrofit measures and the financial options available to pay for them. Building Renovation Passports (BRPs) can help meet this challenge; BRPs typically are masterplans for retrofit and include a record of works and a long-term renovation roadmap that identifies future retrofits and installations to decarbonise the property, along with links to contractors, other service providers and finance options.

They are a way to ensure a holistic and technically sound approach to planning and implementing renovation works. They are also key to prevent 'lock-ins' and can facilitate a step-by-step approach to deep retrofits. The BRPs can be especially useful to help tackle consumer decision-making barriers by providing the information and guidance to enable property owners to improve their properties and reduce emissions. BRPs are being considered as a key solution in the EU; these voluntary passports have also been cited in the 2018 Energy Performance Building Directive[178], to avoid retrofit lock-ins and encourage phased quality deep retrofit. One of the aims of the amended EPBD is to improve energy

[177] https://codema-dev.github.io/map/hertitage-site-map/

[178] Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency

advice services across the EU. Existing BRPs have proven[179] that they can be an effective way of providing renovation advice, whilst also taking into account the long-term vision for the building stock.

The role of BRPs is not only to increase the energy efficiency of buildings but also to increase the uptake of on-site renewables such as heat pumps and solar PV to cover a large part of energy consumption.

BRPs enable building owners to make wise renovation decisions, while also ensuring that measures supporting health and well-being are considered. Suitably heated and cooled buildings help people to be comfortable in their buildings, achieving recommended levels for air quality such as minimum requirements for CO_2 reduces the likelihood of sick building syndrome, adequate lighting improves activity levels, general health and sleep and noise attenuation enables better focus and can help alleviate stress.

Future Energy Demand

Future energy demand for both residential and non-domestic (buildings included are the same as defined in the non-domestic section above) buildings from 2020 to 2030 are described in this section. It should be noted that further information on the effect of buildings on heat and electricity future demands can be found in **Appendix C- Heat Sector Methodology** and **Appendix D – Electricity Sector Methodology**.

Increases in the building sector energy demand to 2030 can be attributed to a number of variables. The main impact on future predicted energy demand can be linked to population growth which is coupled with an increase in both residential and non-residential buildings, which is driven by planning developments. The Economic and Social Research Institute (ESRI) has published population projections and annual average population growth rates for Ireland, this is further broken down by region (table below). For Dublin it has been estimated that the population from 2016 to 2040 would increase annually by an average of 0.9%.

Table 29: ESRI's Population Projections and Annual Average Population Growth Rates by Region[180]

[179] European Commission, Directorate-General for Energy, Zuhaib, S., Volt, J., Fabbri, M., Technical study on the possible introduction of optional building renovation passports : final report, Wouters, P.(editor), Publications Office, 2020, https://data.europa.eu/doi/10.2833/760324

[180] https://www.esri.ie/system/files/publications/RS70.pdf

	Population ('000s)			Annual Average Growth		Population Share	
	2011	2016	2040	2011-2016 %	2016-2040 %	2016	2040
Border	514.9	523.2	589.0	0.3	0.5	11.0	10.5
Midland	282.4	292.3	330.5	0.7	0.5	6.1	5.9
West	445.4	453.1	534.1	0.3	0.7	9.5	9.5
Dublin	1,273.1	1,347.4	1,639.8	1.2	0.9	28.3	29.1
Mid-East	531.1	560.0	707.5	1.1	1.1	11.8	12.6
Mid-West	379.3	385.0	449.4	0.3	0.7	8.1	8.0
South-East	497.6	510.3	585.4	0.5	0.6	10.7	10.4
South-West	664.5	690.6	799.2	0.8	0.7	14.5	14.2
State	4,588.3	4,761.9	5,634.8	0.8	0.8	100.0	100.0
Northern and Western	837.4	847.4	961.6	0.2	0.6	17.8	17.1
Eastern	2,209.5	2,328.5	2,839.2	1.1	0.9	48.9	50.4
Southern	1,541.4	1,585.9	1,833.9	0.6	0.7	33.3	32.5

The National Planning Framework[181] (NPF) for Ireland is projecting a need for 550,000 more homes by 2040, of which 25% of these (137,500 homes) have been planned for Dublin. The NPF has also identified that over recent years there has been an '*ongoing shift in population and jobs towards the east counties*'.

The figure below shows the current average occupancy per dwelling by small area, which has been sourced from the 2016 census. Mean dwelling occupancy was calculated by dividing the total number of occupants per household ("T6_3_TP" or "Total Persons") by the total number of dwellings ("T6_3_TH" or "Total") in each small area. The legend represents the mean number of occupants per dwelling in each small area where red and green indicate a higher and lower number of occupants respectively. In Ireland the average household size was 2.75 people per dwelling[182]; in the Dublin region this is approximately 2.72 people per household.

[181] https://npf.ie/project-ireland-2040-national-planning-framework/

[182] https://www.cso.ie/en/releasesandpublications/ep/p-cp1hii/cp1hii/od/#:~:text=In%202011%20there%20were%20on,increased%20from%202.40%20to%202.48.

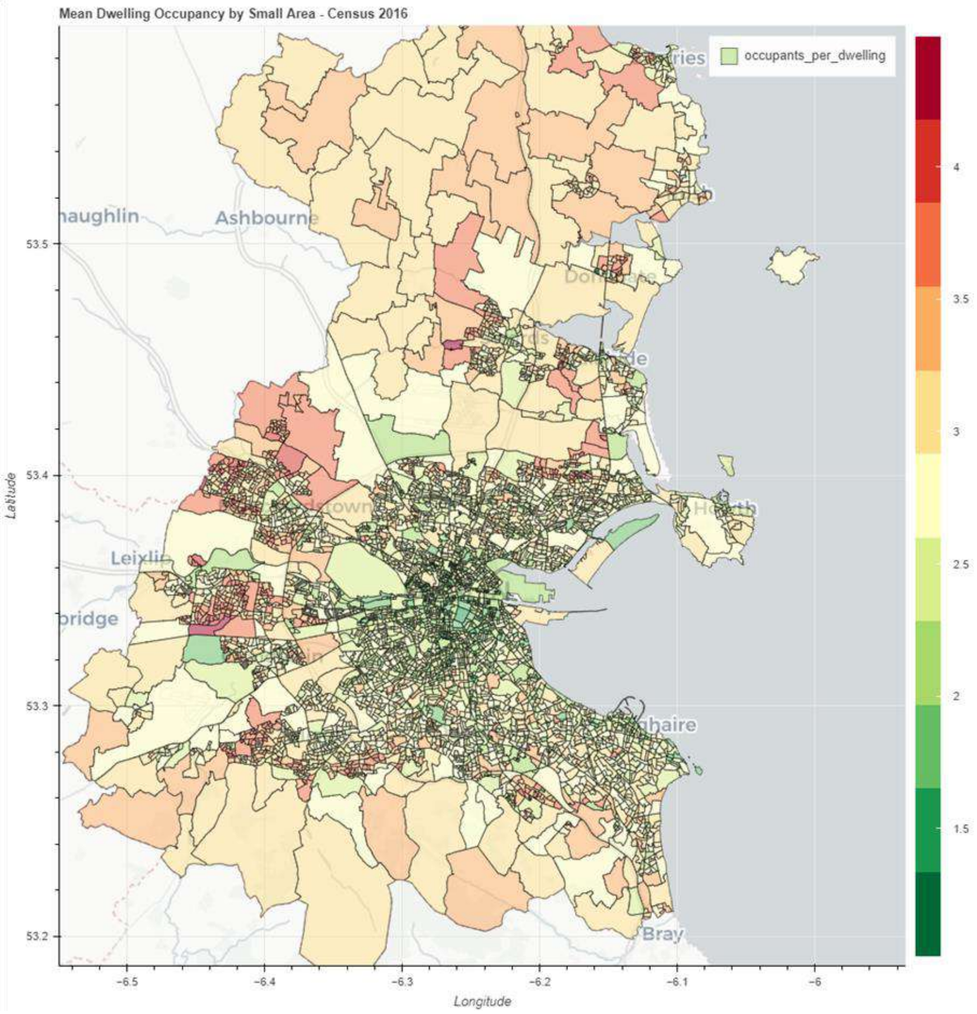

Figure 91: Average Dwelling Occupancy by Small Area in 2016. Source: Census 2016

New Building Regulations

It should be noted that even though the number of buildings (both domestic and non-domestic) are set to increase, building regulations, particularly for new builds, have set out strict guidance on energy performance in buildings.

All new buildings are to be built as to nearly zero-energy building (nZEB) standard, which is defined as a building that has a very high energy performance, as determined in accordance with Annex I of the Energy Performance in Buildings Directive, i.e. the Dwelling Energy Assessment Procedure (DEAP) and Non-domestic Energy Assessment Procedure (NEAP). The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby.

The nZEB standard applies to all new buildings occupied after the 31st December 2020. For public sector bodies, the standard applies to all new buildings owned and occupied by the 31st December 2018. There are transitional arrangements in place in the building regulation which can allow for relaxing of requirements where work on the buildings commenced prior to these dates. NZEB will be implemented in Ireland through Part L of the building regulations.

Two different Part L regulations apply depending on whether the building is a dwelling or not. The relevant regulation for each is listed below:

- Domestic dwellings are regulated under Part L 2019 Conservation of Fuel and Energy - Dwellings
- Non-domestic buildings are regulated under Part L 2017 Conservation of Fuel and Energy – Buildings other than Dwellings

It should also be noted that the Energy Performance in Buildings Directive (EPBD) also includes requirements for electric vehicle charging infrastructure. This is discussed in greater detail in **Appendix E – Transport Sector Methodology.**

Residential Building Compliance

All new residential buildings are required to meet nZEB standards. These requirements state that a Maximum Energy Performance Coefficient of 0.3 and a Maximum Carbon Performance of 0.35 are not exceeded and that a minimum renewable Energy Ratio of 20% is obtained. Compliance with these requirements is demonstrated through the use of the approved DEAP model. This typically corresponds to an 'A3' Building Energy Rating or higher.

In addition to the requirements above, it is also required that the building is in compliance with the following fabric requirements set out in Technical Guidance Document L (TGD L):

- The maximum area-weighted and elemental U-values (as shown in Table 1 of TGD L) are not exceeded in new buildings. Allowable area-weighted average U-values are shown below:
  - Walls and Ground Floor = 0.18 W/m^2K
  - Windows = 1.4 W/m^2K
  - Ground Floor (Underfloor Heating) = 0.15 W/m^2K
  - Flat Roof = 0.20 W/m^2K
  - Pitched Roof or Cold Roof = 0.16 W/m^2K
- Thermal bridging is limited through the adoption of acceptable construction details or alternative methods discussed in section 1.3.3 of TGD L
- Air permeability is less than $5m^3/hr/m^2$
- Where applicable, boiler seasonal efficiency of greater than 90% for gas or oil and 77% for biomass
- Heat pump seasonal efficiency should be in accordance with Ecodesign regulations and controlled in accordance to minimum requirements in Table 2 and Table 3 of TGD L

Non-Domestic Building Compliance

Compliance with nZEB requirements (and Part L of the building regulations) for non-domestic buildings will be demonstrated through modelling the building using the approved NEAP software. NEAP software calculates BERs and demonstrates compliance with Part L using the default calculation tool, the Simplified Building Energy Model for Ireland (SBEMie), or by other approved software packages. NEAP software packages must be approved by the SEAI and can be classified as Dynamic Simulation Modelling (DSM) or Interface for SBEMie.

New non-residential buildings will be required to achieve a Maximum Primary Energy Performance Coefficient of less than or equal to 1 and a Carbon Performance Coefficient of less than or equal to 1.15. There are also additional performance requirements for the fabric, services and lighting as set out in the EPBD. It also introduces a mandatory requirement to utilise renewable sources. The renewable sources must provide 20% of the primary energy use; however, there is flexibility (to 10%) where the building is more energy efficient than the regulations. This typically corresponds to an 'A3' Building Energy Rating. In addition to the requirements above, it is also required that the building is in compliance with the following fabric, heating and lighting requirements as set out in Technical Guidance Document L (TGD L):

- Air permeability of less than $5m^3/hr/m^2$ - alternative approach for confirming compliance is only permitted for large complex buildings with a building envelope area in excess of $160,000m^2$. All air tightness testers are to be certified to I.S. EN ISO 9972 standard.
- Area-weighted average and elemental U-values are less than maximum values in Table 1 of TGD L. Allowable area-weighted average U-values are listed below:

  - Walls and Ground/Exposed Floors = 0.21 W/m^2K

  - Pitched Roof = 0.16 W/m^2K

○ Flat Roof = 0.20 W/m^2K

○ External Doors and Windows = 1.6 W/m^2K

○ Curtain Walling = 1.8 W/m^2K

○ Vehicle Access Doors = 1.5 W/m^2K

○ High Usage Entrance Door = 3.0 W/m^2K

○ Swimming Pool Basin = 0.25 W/m^2K

- Thermal bridging requirements are met through adopting approved details such as those outlined in Table D1 of Appendix D in TGD L
- Boiler efficiency shall not exceed those set out in Table 2 of TGDL and controlled in accordance with minimum standards set out in Table 3 of TGD L (and Table 5 for secondary electric heating systems). In the case where the rated thermal output for space heating is greater than 70kW, a building automation and control system (BACS) should be installed (see section 1.1.2.5 of TGD L)
- Heat pumps and controlled in accordance with minimum standards set out in Table 4 of TGD L
- Specific Fan Power less than values set out in Table 6 of TGD L
- Lighting Efficacy in accordance with limits set out in Table 8 of TGD L

Projecting Future BAU Energy Demands

In order to project future electricity demands, Codema engaged with EirGrid's Energy Modelling team. Making use of EirGrid's support and report, All Island Generation Capacity Statement 2019 -2028[183], the growth factors used in this analysis were developed using forecasted economic growth from ESRI in conjunction with historical demand data. The demand forecasts also had to account for increases in both the housing stock and commercial properties in future years, whilst also considering the negating effects of increased energy efficiency in buildings.

Conveniently, these demand estimates have been provided under three key headings of residential, commercial and data centres, each of which had their own respective growth factors. Interestingly, the energy demand for 2021 was set to decrease from 2020, due to the economic downturn from the COVID-19 pandemic; however, this is set to revert and continue in an upward trend from the year 2022.

These electricity growth factors were combined with projected heat demand growth factors that have been developed by Codema. Heat demand projections accounted for residential and non-residential (commercial and industry) buildings and the increase in new buildings (both residential and non-residential). Future scenarios also accounted for increased energy efficiency in buildings with fabric upgrades and the rebound effect, and buildings with no fabric upgrades. For this BAU, it was assumed that fabric upgrades will be undertaken to bring buildings to threshold U-Values (these threshold U-Values are described in detail in the following section **Potential for Building Efficiency and Carbon Savings for the Dublin Region**), thus these projected figures might be slightly lower than future building demands.

Overall, for the building sector, it has been estimated that the business-as-usual energy demand is likely to increase by 5% by 2030 and a total increase of 14% by 2050 (from 2020 figures). The residential sector is set to increase by 11% over the 30 year period, this means that the future BAU residential energy demand in 2050 is estimated to be 11,529 GWh, whilst commercial buildings are set to increase by 21%, resulting in a future BAU demand of 6,152 GWh by 2050. Data centres and the increase in energy demand generated by these proposed developments will be discussed in further detail in **Appendix D – Electricity Sector Methodology.**

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[183] https://www.eirgridgroup.com/site-files/library/EirGrid/EirGrid-Group-All-Island-Generation-Capacity-Statement-2019-2028.pdf

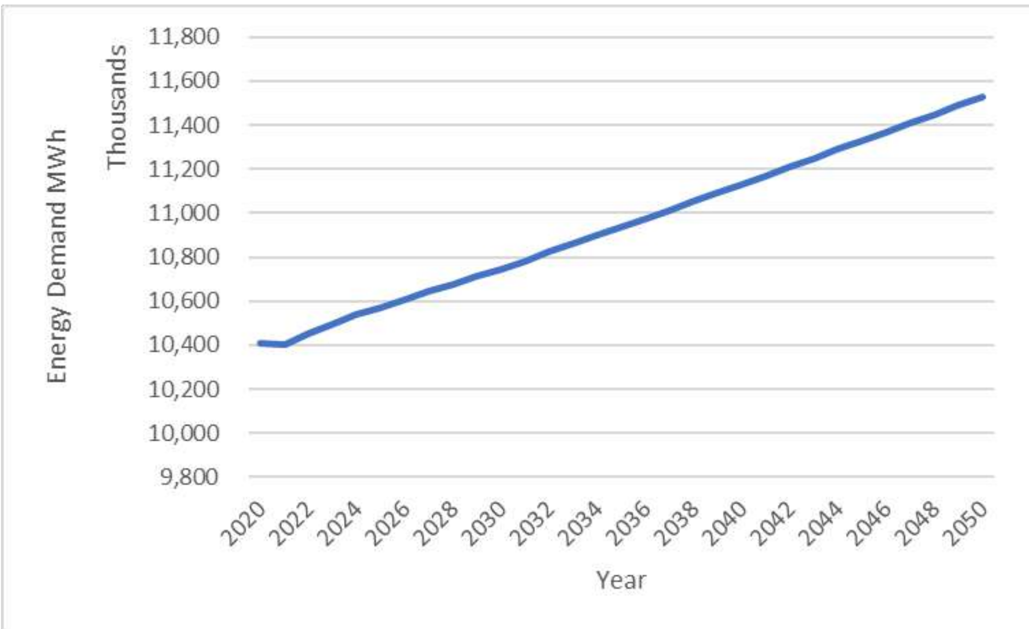


Figure 92: Dublin's Residential Energy Demand Forecast

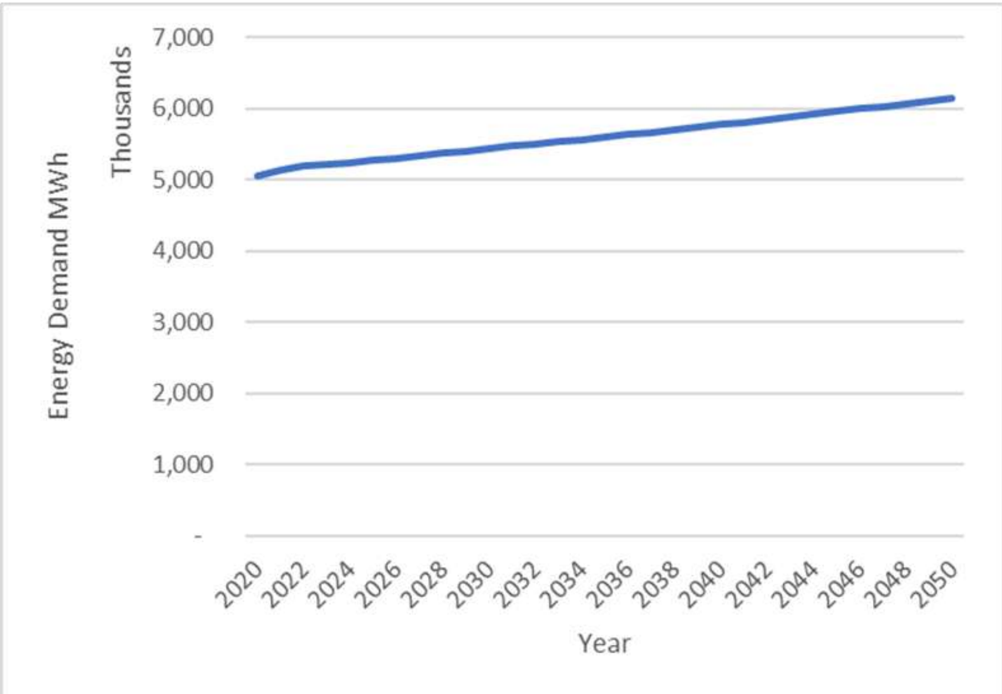


Figure 93: Dublin's Commercial Energy Demand Forecast

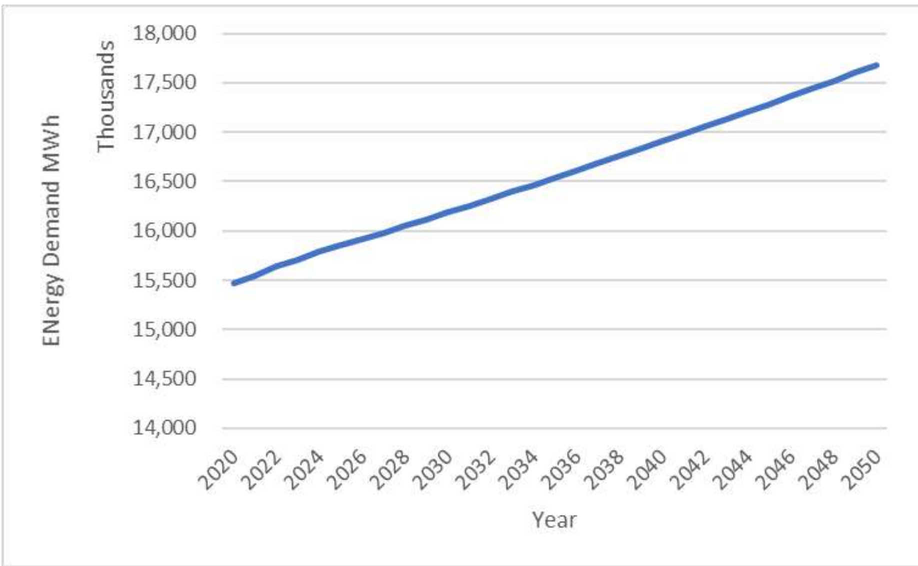


Figure 94: Total Building BAU Energy Demand from 2020 to 2050

Potential for Building Efficiency and Carbon Savings for the Dublin Region

This section of the report sets out how potential carbon savings from building fabric upgrades are determined. The level of building stock and energy demand information at such spatial resolution allowed for the identification of feasible building fabric upgrades for residential buildings. Since building fabric information for non-domestic buildings was very limited, non-domestic building fabric upgrades were not considered. However, upgrades in heating technologies for this sector are accounted for in the Heat Section and it was assumed that commercial buildings in each small area would use the predominant heating technology for Dublin gas boilers.

Other avenues explored to identify non-domestic building fabric information included the assumption that commercial properties in each small area would have a similar building fabric as the most common residential dwelling in the small area, i.e. the commercial buildings would have been built during the same period and using the same building materials and have the same fabric as those found in the residential sector. However, this assumption was not viable as it would have led to other less realistic assumptions to be made on window, roof, and wall areas (to generate fabric upgrade costs), thus this assumption was deemed not worthwhile.

It should be noted that the viability of specific heat and electricity technologies used to further decarbonise both the domestic and non-domestic sectors, are discussed in detail in **Appendix C - Heat Methodology Sector** and **Appendix D - Electricity Methodology Sector.**

In order to improve energy efficiency and reduce emissions from the building sector, the building energy model (discussed in **Appendix A – Energy Modelling**) was setup in such a way that it can model the impact that building fabric upgrades have on:

- BER ratings
- Heat Pump Viability
- Energy Savings
- Cost by Measure

The model makes use of current buildings' fabric U-values. U-values measure the effectiveness of a material as an insulator, meaning it determines a material's heat loss. The well insulated material will have a low U-value and thus, will lose less heat. The building stock's U-values for walls, roofs and windows determine how much heat is lost through the building fabric.

In order to retrofit a building to be able to meet a minimum B2 BER it is necessary to first reduce its fabric and ventilation heat loss by retrofitting it. As the cost of retrofitting is case specific and somewhat uncertain, lower and upper bound estimates were calculated based on a cost per unit area derived from the TABULA project report[184].

The Intelligent Energy Europe (IEE) TABULA project's aim was to create a building typology for each of the member states participating in the project, of which Ireland made a part of. For Ireland, 34 typical Irish dwelling types were identified and the typical existing Irish residential buildings were selected by assessing the ranges of construction types and building periods using the DEAP software and SEAI's national BER database. The 34 Irish dwelling types are spread across different periods built and include apartments, detached, semi-detached and terraced houses. They also include a range of building wall types including stone, mass concrete, solid brick, hollow block, cavity and timber frame with varying insulation levels (U-values). For each dwelling type, the cost of the recommended measures is shown (these include reducing typical material's U-values to reduce heat losses). The costs used are average industry costs gathered from a survey of market prices.

In order to estimate costs of building fabric upgrades, typical material improvement upgraded costs (U-value improvements in €/m^2), derived from the TABULA project, were used. To model the retrofit impacts and costs, the following assumptions were made:

- **Threshold U-Value** - the U-Value below which no dwelling is likely to retrofit that fabric component
- **Target U-Value** - the U-Value all buildings must obtain upon retrofitting
- **Cost Lower & Cost Upper** - cheap and expensive scenarios

Table 30: Fabric U-Values and Costs

Component	Threshold U-Value [W/m²K]	Target U-Value [W/m²K]	Cost Lower [€/m²]	Cost Upper [€/m²]
Wall	1	0.35	50	300
Roof	1	0.25	5	30
Window	2	1.4	30	150

The threshold values were determined by inspection of the following distributions which were created based on the synthetic building stock.

[184] Loga, T., Stein, B. and Diefenbach, N., 2016. TABULA building typologies in 20 European countries—Making energy-related features of residential building stocks comparable. *Energy and Buildings*, *132*, pp.4-12

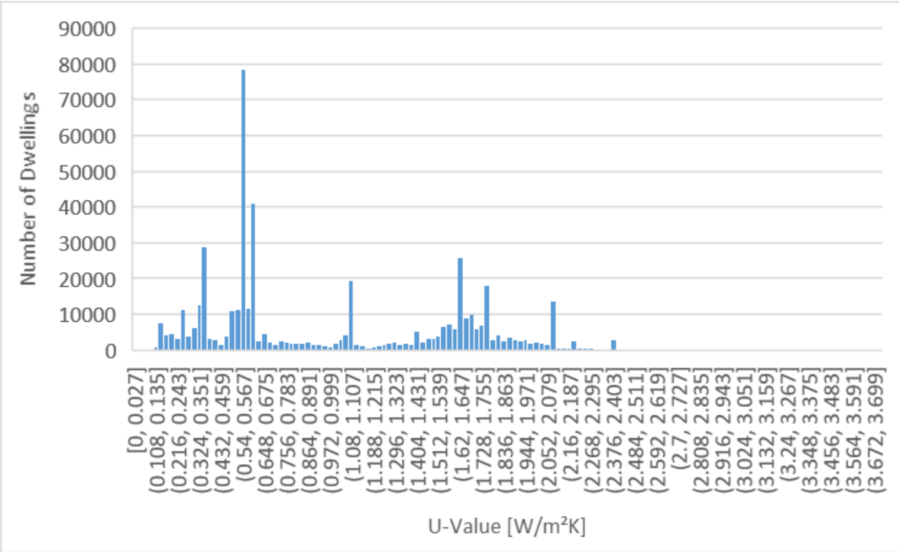


Figure 95: Wall U-Value Distribution

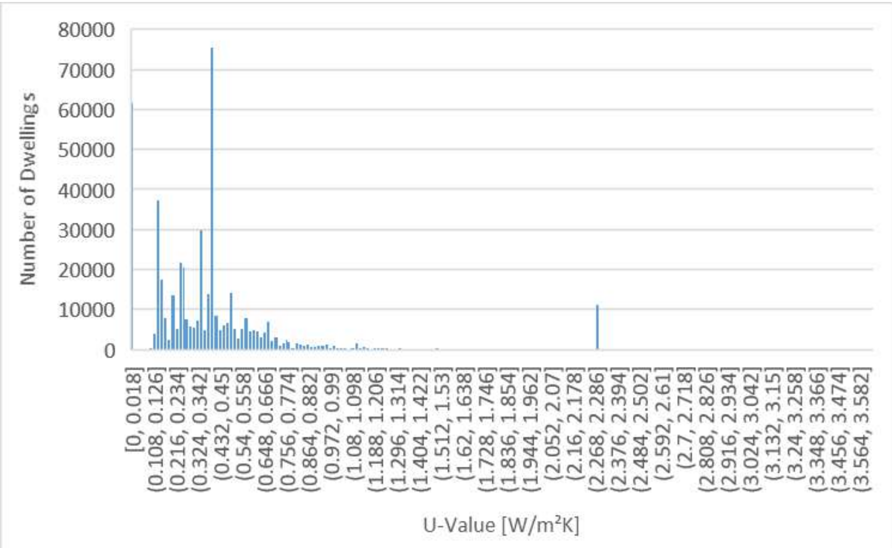


Figure 96: Roof U-Value Distribution

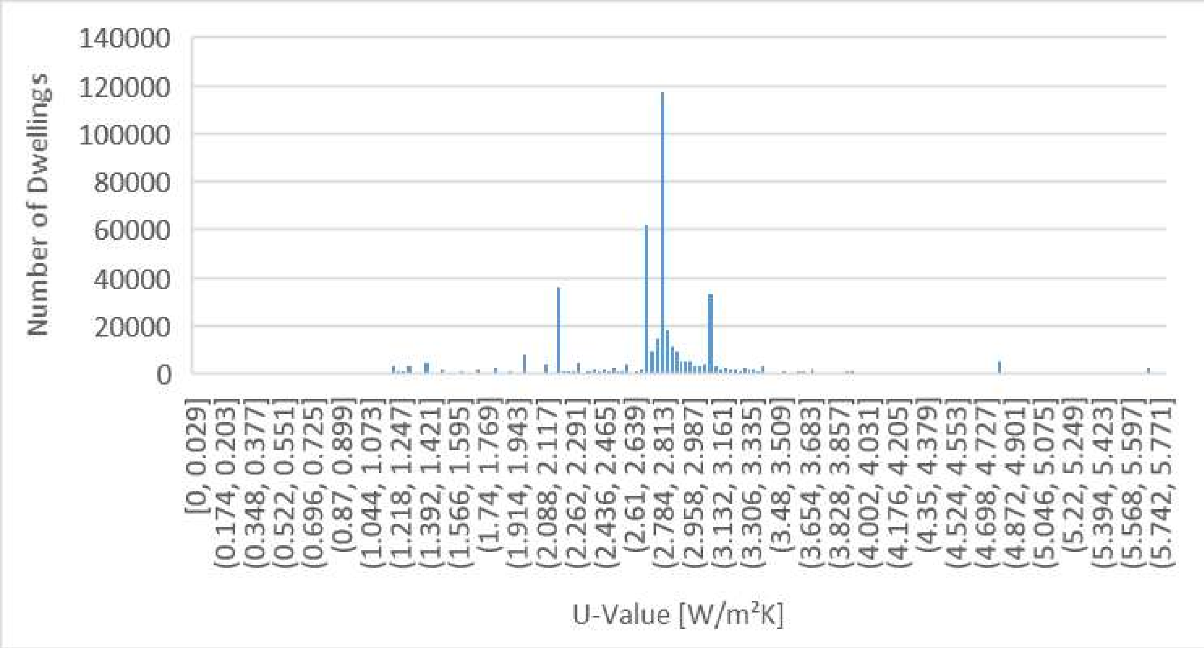


Figure 97: Window U-Value Distribution

It should be noted that not all dwellings are likely to be retrofitted. Some buildings with borderline fabric properties may decide that the additional cost of retrofitting is too costly. To approximately reflect the likelihood of retrofitting, Codema has considered two scenarios: the ‘threshold’ scenario and the ‘no threshold’ scenario. In the “threshold” scenario, only buildings that have a heat loss indicator (HLI) greater than two (not heat pump ready), have a fabric u-value above an approximate threshold (identified in table xx) or have been built after the year 1919 are considered viable for retrofitting. Whilst for the “no threshold” scenario, all buildings that have an HLI greater than two (are not yet heat pump ready) are considered for building fabric retrofits.

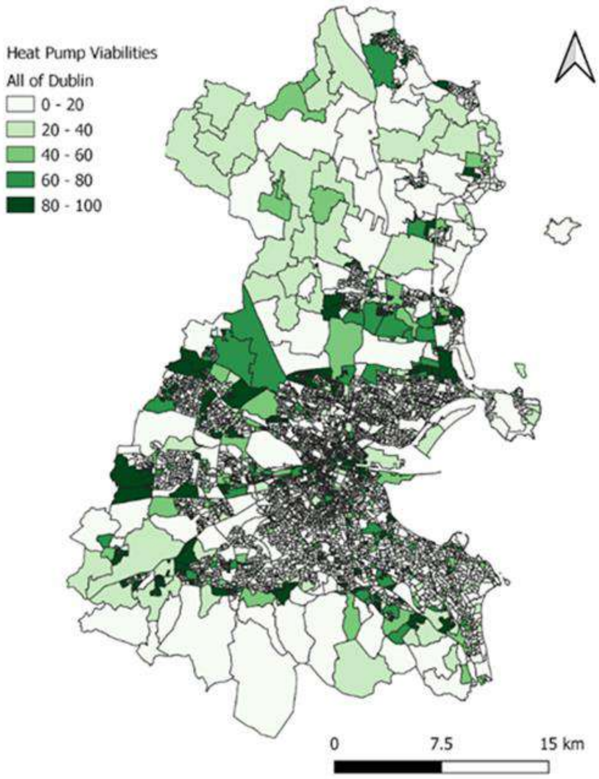


Figure 98: Current Heat Pump Viability in Dublin

Also, it should be noted that to account for the rebound effect (discussed in further detail in the previous section, Barriers to Energy Efficiency Upgrades) it was assumed that all retrofitted buildings save 30% less energy than might be theoretically predicted to broadly reflect the findings of Aydin et al[185] of a rebound effect of 26.7% among home-owners and 41.3 % among tenants. The results of this are shown in the tables below.

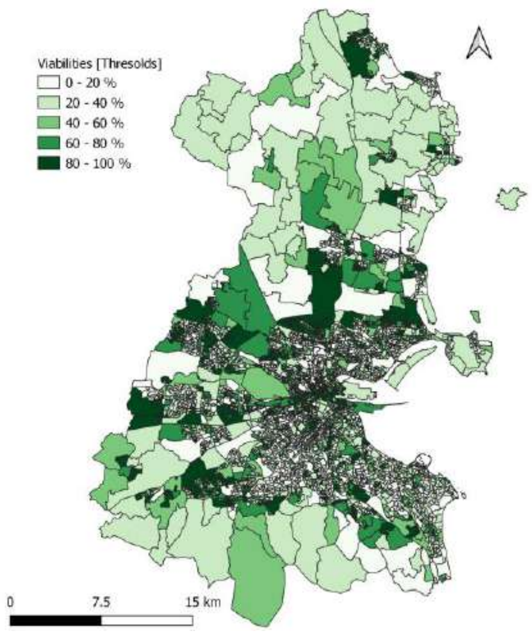
<u>“Threshold” scenario</u>

Table 31: ‘Threshold Scenario’ - Building Fabric Upgrade Costs

Measure	Lower Bound Estimate	Upper Bound Estimate	Number of homes retrofitted
Walls to 0.35 W/m²·K	M€700	M€4200	166,966
Roofs to 0.25 W/m²·K	M€6	M€36	18,360
Windows to 1.4 W/m²·K	M€186	M€930	314,533
All Measures	**M€892**	**M€5166**	**317,577**

Table 32: ‘Threshold Scenario’ - Building Fabric Upgrade Energy Saving & Emission Reduction

Savings	Theoretical Savings	With Rebound Effect Considered
Energy [TWh/year]	1.72	1.14
Emissions [tCO_2]	366,000	241,500



[185] Aydin, E., Brounen, D. and Kok, N., 2013. *The Rebound Effect in Residential Heating*. https://www.tilburguniversity.edu/sites/tiu/files/download/The%20Rebound%20Effect_EA300813.pdf

Figure 99: Heat pump viability following upgrades - No Threshold

<u>"No Threshold" scenario</u>

Table 33: 'No Threshold Scenario' - Building Fabric Upgrade Costs

Measure	Lower Bound Estimate	Upper Bound Estimate	Number of homes retrofitted
Walls to 0.35 W/m²·K	M€1336	M€8021	320,044
Roofs to 0.25 W/m²·K	M€91	M€545	320,044
Windows to 1.4 W/m²·K	M€962	M€962	320,044
All Measures	**M€1,620**	**M€9,529**	**320,044**

Table 34: 'No Threshold Scenario' - Building Fabric Upgrade Energy Saving & Emission Reduction

Savings	Theoretical Savings	With Rebound Effect Considered
Energy [TWh/year]	2.44	1.60
Emissions [tCO_2]	518,000	342,000

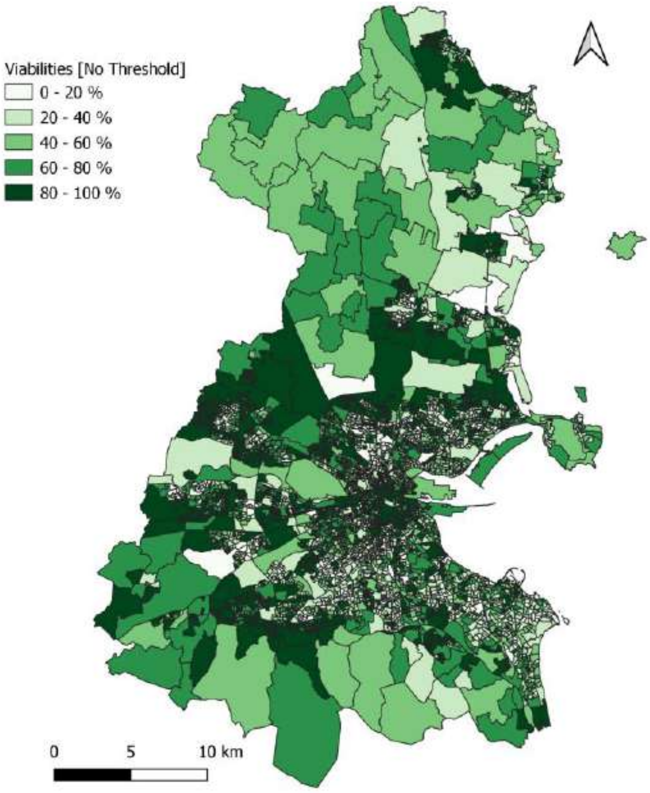


Figure 100: Heat pump viability following upgrades - No Threshold

Once retrofit, these buildings are sufficiently energy efficient to allow heat pumps to be installed, as their heat losses will have been reduced to the specific requirements as specified by SEAI's guidelines[186] for these heating technologies. Further detailed information on building retrofits and reduced heating demands, maps showing heat pump and district heating viable buildings can be found in **Appendix C – Heat Sector Methodology.** Online maps showing the effects of retrofitting Dublin's residential housing stock can be found on Codema's Tableau[187]. These maps show residential energy demands for Dublin, along with the associated retrofitting energy savings based on an archetypal modelling approach. This approach divided the stock into dwelling types and categorized them as either pre or post retrofit based on whether their BER rating was greater or less than B2, in accordance with SEAI standards.

[186] https://www.seai.ie/publications/Technical_Advisor_Role.pdf
[187] https://public.tableau.com/app/profile/oisin.doherty/viz/ResiDemandRetrofitted/Sheet1

Appendix C - Heat Sector Methodology

Heat Source Description

This section of the report provides a general description of each of the heat sources investigated in creating the Dublin region heat source map.

Category	Source	Description
Commercial	Flue gas heat recovery	Hot flue gases are produced when fuel or waste gases are combusted in boilers, combined heat and power units, and thermal oxidisers. The heat from these gases can be captured and used to heat water for the DH system. The quantity of heat available depends on the flue gas temperature and flow rate which varies based on the number, size and type of heating unit being used and the heat or waste gas combustion load it needs to serve.
	Industrial process heat recovery	Many industrial processes result in the production of waste heat which does not take the form of exhaust gases from combustion. In this study these include industrial sites, breweries, pharmaceutical, metal processing plants. Details of individual process heat producers were not available for these sites and so the waste heat was taken as being the heat rejected to sewer for each site.
	Commercial / Industrial sites with CHP	Some commercial and Industrial sites will have on-site cogeneration / combined heat and power (CHP) units to provide both heat and electricity to the site. Connecting existing CHP plants to a DH network could result in mutual benefits for both the CHP operator and the DH network. By increasing the potential heat demand for the CHP, its run hours and electricity generation can be increased, the heat rejection and associated costs are reduced, and the CO_2 emissions are reduced due to greater electrical generation and use of the heat that would previously have been rejected.
	Commercial / Industrial cooling (e.g. data centres, cold storage facilities, hotels, offices)	Certain commercial and industrial buildings require a significant amount of cooling which results in significant heat rejection. This heat can be converted to a usable temperature for a district heating system via a heat pump. The types of buildings in this study use this cooling for comfort cooling, IT equipment cooling and food storage & refrigeration, etc. The main building types assessed were data centres, cold storage facilities and industrial sites. The quantity of heat available will vary depending on the cooling system used and the operational cooling requirement.

	Direct liquid cooling in Data Centres	In some data centres, the cooling system utilises direct liquid cooling of servers rather than cooling of the air around the servers as discussed above. This is a more efficient means of providing cooling and also from a DH perspective provides a higher grade heat for use in a network.
Infrastructural	Power plant (EfW or Other)	Power plants burn fuel to generate electricity. Their electrical generation efficiency is typically between 30% and 50% depending on the technology and fuel being used. This process also generates high-grade waste heat. There are two main types of conventional power plant; Open Cycle Gas Turbines (OCGT), and Combined Cycle Gas Turbines (CCGT). In the case of OCGT, the hot exhaust gas is rejected to the atmosphere through a flue system. In the CCGT some heat is rejected to the atmosphere via a flue system and some is rejected to the steam condenser. There are also less conventional power plants called Energy from Waste (EfW) facilities, a.k.a. Waste to Energy (WtE), which combust waste to produce steam for the turbines to generate electricity (Steam Cycle). The waste heat in an EfW facility can be captured from the flue system and the steam condenser.
	Electrical transformers	Electrical transformer substations convert electrical power from one voltage to another. During this process a certain amount of electrical power is lost and converted into heat. These transformers are kept cool and insulated by being immersed in insulation oil or by fans in air-cooled transformers. The heat from these transformers can be extracted for use in a district heating system.
	Landfill (biogas & waste heat)	Landfill gas is formed when biodegradable material in the landfill decomposes. This chemical reaction also gives off heat which can be captured via a closed loop collector connected to a heat pump. The landfill gas can also be used to fuel a boiler or CHP unit to generate heat and electricity.

	WWTW (waste heat, biogas/sludge incineration)	Waste water contains a certain amount of organic matter. When this material breaks down it can form biogas which can be used to fuel a boiler or CHP unit to generate heat and electricity. Heat can also be extracted from the waste water itself in the same way that heat is extracted from surface water. This heat extraction usually takes place in the WWTW tertiary tanks via a heat exchanger connected to a heat pump.
	Sewage pipes waste heat	Sewage in underground sewage pipes contains heat which can be extracted through various types of heat exchanger. This can provide heat at a usable temperature for a district heating network by passing it through a heat pump.
	Electrolyser waste heat	In the future, electrolysers which use green electricity to produce green hydrogen for use in Industry as a feedstock but also potentially as a future fuel for aviation, backup power generation, and shipping are typically 60% efficient. The electric power that is lost in the process is lost as heat. This heat could be captured to supply DH networks and thereby increase the over efficiency of the process.
Environmental	ASHP	Air source heat pumps extract heat from the outside air. These heat pumps give lower efficiencies than WSHPs or GSHPs due to the comparatively lower heat source (air) temperature during the main heating season.
	Surface water (rivers, lakes, canals)	Surface water sources such as rivers and canals contain a certain amount of heat which can be extracted via a heat pump. The quantity of heat that can be extracted is dependent on the river's flow and water temperature and maximum allowable reduction in temperature that can be achieved without any negative impact on the environment.
	Seawater	Seawater source heat pumps utilise the thermal energy stored in the sea. This heat can be extracted via a heat pump. The quantity of heat that can be extracted is dependent on the maximum allowable reduction in temperature that can be achieved without any negative impact on the environment.

	GSHP	Ground source heat pumps extract heat from the ground. Heat can be extracted from open or closed loop heat pumps, the former using aquifers, the latter boreholes or horizontal collectors. The amount of heat that can be extracted depends on the quantity of suitable land that is available to install collectors or in the case of open loop systems, the maximum ground water extraction rate.
	Deep geothermal	The earth's temperature increases the deeper you drill. Deep geothermal systems extract this heat by pumping water out of deep boreholes to the surface where it can be used, once the heat is extracted this water is then pumped back into the earth. Certain areas have a higher heating potential than others based on their geological composition. In areas where source temperatures of greater than 60°C can be achieved the DH system may not require a heat pump as the water extracted is already at a usable temperature. In other areas high-efficiency heat pumps can be used to raise the temperature to the required level. This study looks at the potential of such systems within South County Dublin. Geothermal energy has proven to be secure, environmentally sustainable and cost effective over long time periods. The complete security of supply of geothermal energy makes it a particularly attractive energy solution. High-temperature geothermal resources are commonly found in volcanic regions near active tectonic plate boundaries (e.g., Iceland). Despite its position far from any plate boundaries, Ireland has recognised potential for deep geothermal energy in sedimentary basins in the south and east, and Northern Ireland (SLR's Play Fairway Analysis report, 2011; GeoDH report, 2014; outputs of IRETHERM project, 2016). In recent decades, improvements in drilling and geothermal technologies, coupled with policy-driven pursuit of secure and low-carbon energy sources, has led to the development of geothermal district heating in several low-temperature geothermal settings in the EU (e.g., France, UK, Denmark and the Netherlands).
	Mine water	Mines are prone to flooding by ground water. This ground water is warmer than surface water due to the increased ground temperatures at greater depths, this higher temperature results in an increase in the Coefficient of Performance (CoP) when passed through a heat pump to convert the heat to a usable temperature. The quantity of heat that can be extracted depends on the maximum extraction flow rate and the temperature of the groundwater.

Heat Source Assessment Methodology for District Heating

This section of the report discusses the approach used in estimating the available capacity of heat from each source and how it is represented on the heat source map.

It should be noted that the heat source capacity is mapped as available heat as opposed to heat delivered to the network to avoid any unfair bias due to assumptions regarding how efficiently this heat might be collected, upgraded etc.

Category	Source	Description
Commercial	Flue gas heat recovery	The flue gas heat recovery was estimated in kW for large Industrial sites using the flow rate of exhaust gas through the flue, the temperature of the exhaust gas and the minimum temperature at which the gas can be expelled from the flue without causing issues with pluming or problems with corrosion[1]. The flue gas flow rates were taken from the industrial facilities Industrial Emissions/Integrated Pollution Control licence documentation available from the Environmental Protection Agency. In the cases where this information was superseded by EU ETS data, the verified ETS annual carbon emissions were used to calculate a flue gas flow rate based on the percentage CO_2 by volume[2] and using the relative gas densities at 200°C. Where flue temperatures were stated in the IPC licence these were used, in the cases where no flue temperature was specified an average flue temperature for the specific heat technology (e.g. steam boiler, CHP, Thermal Oxidiser etc.) was assumed. These average assumed temperatures were calculated based on the temperatures available in other IPC licence documents. No flue gas temperatures were stated for spark ignition engine CHPs in the IPC licences, hence, exhaust temperature from datasheets were used. Flue gas temperatures for CCGT and Steam Cycle plants were taken from a report on heat recovery steam generators[3]. The assumed minimum flue gas exit temperatures used were chosen to prevent corrosion problems in the flue, based on the fuel being used and to avoid pluming of the flue gases. When estimating the potential kW of heat recovery based on the annual carbon emission (i.e. from EU ETS data) assumptions on the annual run hours of the heating plant had to be made. Power plants were assumed to have 24/7 operation apart from two weeks for maintenance work per year. Industrial heating plant was assumed to operate 10 hours per day, seven days per week and assumed 2 weeks of maintenance per year. These heat sources are represented on the heat source map as individual point locations. Where possible, these points are located at the known location of the flues within the site itself.

	Industrial process heat recovery	Given the limited information available for specific individual process streams on site, the heat recovery potential for these individual processes could not be assessed. However, one potential low-grade heat source that could be estimated was the capture of waste heat from the sites' sewer water. Where available the maximum sewer water flow rates (m^3 per hour) and maximum sewer water temperatures were taken from the industrial facilities Industrial Emissions/Integrated Pollution Control licence documentation available from the Environmental Protection Agency. This provided enough information to calculate an estimate of the potential heat extraction from the industrial process waste heat sent to drain. These heat sources are represented on the heat source map as individual point locations at the point of discharge provided on the EPA licence.
	Commercial / Industrial sites with CHP	There are numerous commercial and industrial sites which operate combined heat and power (CHP) plants of various types within the study area, including gas turbine and spark ignition engines. For each CHP plant the thermal capacity was taken from various sources including the plant operator, IPPC licence documents and planning applications. Further details of these units such as the typical operation hours and type of building being supplied has also been provided for some of these units through engagement with operators. These CHP units are represented on the map as individual point locations.
	Commercial / Industrial cooling (e.g. data centres, cold storage facilities, hotels, offices)	Certain buildings have significant cooling loads. Cooling is primarily required to provide comfort cooling (i.e. in offices), process cooling, refrigeration and dehumidification. Cooling systems reject heat while in operation. The quantity of heat rejected is dependent on the building cooling load and the cooling systems seasonal efficiency. These cooling system sources are represented on the GIS map as individual point locations.

Infrastructural	Power plant (EfW or Other)	The quantity of heat that can be extracted from a power plant depends on its heat to power ratio, thermal efficiency and its load profile. There are three different types of power plant included in this study; Combined Cycle Gas Turbine (CCGT), Open Cycle Gas Turbine (OCGT), and Steam Cycle (EfW) plants. Details of the thermal input and electrical generation capacities for each CCGT and OCGT power plant were available online from the ESB[4] and EPA websites. Details of the heat to power ratio and capacity for the EfW facility in Poolbeg were based on figures from similar facilities in Europe. Extracting heat at a usable temperature from EfW and CCGT plants will have an impact on their electricity production. This relationship between electricity production and heat production is represented by the plant's z-factor. These heat sources are represented on the heat source map as individual point locations
	Electrical transformers	Electrical transformer sub-stations convert electrical power from one voltage to another. During this process a certain amount of electrical power is lost and converted into heat. These transformers are often kept cool and insulated by being immersed in insulation oil. The heat contained in this oil can be extracted for use either directly if the temperature is high enough or by passing it through a heat pump depending on the temperature of the oil. The quantity of heat that can be extracted depends on the transformers' efficiency (heat losses), capacity and load factor. The load factor of the transformers is generally in the range of 40% - 60% based on data available on the capacity and loading of high voltage transformers[5]. The efficiency of these transformers was assumed at 99.6% based on discussions with ESB. The transformer capacity was also taken from the ESB's transformer capacity and load information. The average temperature of the oil was assumed to be 55°C for the assumed load factor, this is based on transformer temperature analysis carried out for similar projects in the UK[6] and has been deemed comparable by the ESB, to their transformer oil temperatures at this load factor. This heat may be used directly in DH systems that can provide heating at these temperatures, however, in a large proportion of buildings in Ireland, higher supply temperatures will be required, and these can be achieved very efficiently using a heat pump. These transformer heat sources are represented on the heat source map as individual point locations. These locations were provided by ESBI.
	Landfill (biogas & waste heat)	The landfill sites identified in South Dublin have been found to contain inert construction and demolition waste. As this waste is inert it does not support the chemical reactions which generate heat or landfill gas. Therefore, these sites have not been included on the map.

	WWTW (waste heat, biogas/sludge incineration)	The waste heat capacity estimates are based on annual average temperatures for tertiary tanks of similar waste water treatment sites and the typical flowrate (m^3/day) was taken from EPA licence data. The maximum temperature reduction (delta T) of the effluent was assumed based on technical constraints, i.e. temperature below which issues with freezing on the evaporator of the heat pump may occur. The potential biogas production was also estimated as a means of assessing suitability for the use of biogas CHP or boilers. This was calculated based on the tonnes of dry solids per annum. These WWTW heat sources are represented on the heat source map as individual point locations. These locations were plotted using the grid reference coordinates stated in the EPA licences.
	Sewage pipes waste heat	The quantity of heat that can be extracted from a sewer depends on the flow and temperature of the sewer water passing through it. Details regarding flow and temperature were taken from EPA licence documents. The maximum temperature reduction (delta T) was assumed based on technical constraints, i.e. temperature below which issues with freezing on the evaporator of the heat pump may occur. In cases where the sewer is feeding a waste water treatment works (WWTW) a smaller delta T may be assumed to ensure a high enough temperature is maintained to prevent the biological activity required for treatment of the water from being adversely affected. These sewage pipes heat sources are represented as individual points on the GIS map these locations are based on discharge point coordinates in the EPA licences
Environmental	ASHP	Air-source heat pumps will typically have a lower average efficiency than heat pumps which utilise other sources such as surface water, sewer water, industrial waste heat, ground or geothermal and mine water but benefit from having a readily available heat source. The main technical constraint to the roll out of ASHPs is that with a lower efficiency (particularly during the heating season) they would require greater electrical grid capacity to supply the same heating capacity as heat pumps which utilise other sources.

	Surface water (rivers, lakes, canals)	The kW of extractable heat was estimated using an assumed delta T and the flow rates (95%tile flow) available from the Environmental Protection Agency for water measurement stations that measure water bodies that flow into Dublin. The dry weather flow rates of surface water discharge points from wastewater treatment plant's discharge authorisation documents were also used where available. The 95 %tile and dry weather flows were used for this calculation as the environmental impact of overall river water temperature (as discussed in greater detail below) was seen as the critical limiting factor. In areas where fisheries are not at risk it may be more pertinent to use the mean river flow to estimate the heat capacity – which would result in an estimated seven-fold increase in the extractable heat from the river. To reduce the risk of adverse effects on the local fish stocks a maximum reduction in river water temperature (delta T) due to heat extraction of 2°C was assumed (this figure was chosen as it is between 1.5°C and 3°C which are the permissible limits on thermal variance set out in the EU Directive[7] for Salmonid and Cyprinid waters respectively and is also the figure used in similar studies in the UK[8]). It should be noted that not all surface water features are classified as fisheries and in these cases a larger delta T may be allowed as these are limited more by technical constraints i.e. for open loop systems reducing the river water to below 3°C may cause issues with freezing on the evaporator side. River water temperatures were available from integrated water quality assessment reports published by the EPA for the North Western & Neagh Bann, Monaghan & Louth and South East Ireland river basins. These figures were used to get an average river temperature for each month of the year. These average temperatures were used to estimate the seasonal CoP that can be achieved by a proposed heat pump. This heat source is mapped as a point location on the specific water body which represents the location of where the flow was measured. It can therefore be assumed that at any position along the water body downstream of this point has a heating capacity that is at least equivalent to this kW figure.
	Seawater	The heat capacity that can be provided from the sea is only really limited by the abstraction rate in cubic metres per second (m3/s). For the section of the Irish Sea off the coast of Dublin, Codema has calculated this heating capacity at 27.7 MW per m3/s using the minimum average monthly sea temperature. It should be noted that in order to put a representative limit on what is an almost unlimited heat source, Codema looked at the capacity of DH systems currently utilising sea water as a heating source across Europe and assumed similar-sized plants could, on average, be located at intervals of 1km along the coastline.
	GSHP	Shallow ground source heat pumps (using horizontal collector or energy piles) are generally more suited to individual building heat supply given the land area requirement for these installations and have not been included in this analysis. Larger closed loop systems are discussed further in the deep geothermal section.

	Deep geothermal	The heating capacity from the section of the Dublin Basin which is within the Dublin county boundary was estimated using a software model called DoubletCalc which has been developed by TNO in the Netherlands. It should be noted that this capacity estimate is based on an open-loop system where groundwater is extracted through a production well and reinjected back into the ground via an injection well. Closed-loop wells (where a thermally-efficient fluid is circulated within the borehole column) are also suitable for geothermal heating in certain areas but have not been analysed as part of this study. An indication of the suitability of certain areas to different types of geothermal heat supply can be found at http://maps.seai.ie/geothermal/ Dublin Basin contains sedimentary carbonate rock that has a tight matrix (groundmass which consists of tightly compacted material), so the permeability has been assumed to be heavily dependent on fractures and karst. This is somewhat at odds with the DoubletCalc software, which has been developed for homogeneous, isotropic primary porosity media (sandstones). DoubletCalc manual (2014) https://www.nlog.nl/sites/default/files/6ab98fc3-1ca1-4bbe-b0a2-c5a9658a3597_doubletcalc%20v143%20manual.pdf. However, TNO have had some success with using DoubletCalc to predict the output of a doublet in a Dinantian limestone reservoir (Reith, 2018). Data sets in the Dutch study were collected from very similar geological and geothermal conditions to those found in the Dublin Basin, with a median permeability of around 500 mD and a lower median Net to Gross of 55%. Figures taken from TNO report on Californie project: https://www.rvo.nl/sites/default/files/2017/01/Advies_garantiefonds_aanvraagAARD03001Californie.pdf Providence Resources have recently reported average permeabilities of “10s of mD” for a carbonate reservoir in the Porcupine Basin (North-eastern Atlantic Ocean) at depths of 3 km, but with a high Net to Gross of 90%. Based on these real values measured in deep limestone and staying within the normal range of values for hydraulic conductivity in carbonates (Freeze and Cherry, 1979), we have used minimum, median and maximum permeability values of 5, 50, and 500 mD respectively (with the aim to be conservative) for the Dublin Basin. We have used a median Net to Gross of 55% based on Dutch capacity models. It has been assumed that a geothermal gradient of approximately 32 °C/km is realistic based on previous temperature measurements in the Dublin Basin (GT Energy Newcastle project, 2008). This would suggest that a heat pump may not be required to supply a DH network at a usable temperature. Certain assumptions regarding the structure of the wells and reservoir have been made to estimate the heat capacity. These include: ● Reservoir assumed to be 500 m thick. ● Top of aquifer assumed to be at 2000 m below sea level. ● Both wells in the doublet are drilled vertically for 1000 m and then deviate at 45 degrees to a final vertical depth of 2500 m. ● At aquifer level, the wells are 1000 m apart to prevent thermal breakthrough. ● Water is re-injected at a temperature of 35°C. Pump characteristics from Dutch borehole models were adopted for this estimate. The Dublin Basin is represented as a geographical area (grey polygon) on the heat source maps. Through our high-level analysis it has been estimated that 129 sets of deep geothermal doublets could be drilled in the Dublin region. Based on the above assumptions the total capacity of all 129 doublets could range between 86 MW (at 90% probability) and 437 MW (at 10% probability).

		The Dublin Basin is represented by a large grey polygon on the GIS map.
	Mine water	There was one mine identified in the Dublin region but this was not located near any heat demands and therefore was not assessed as part of this exercise.

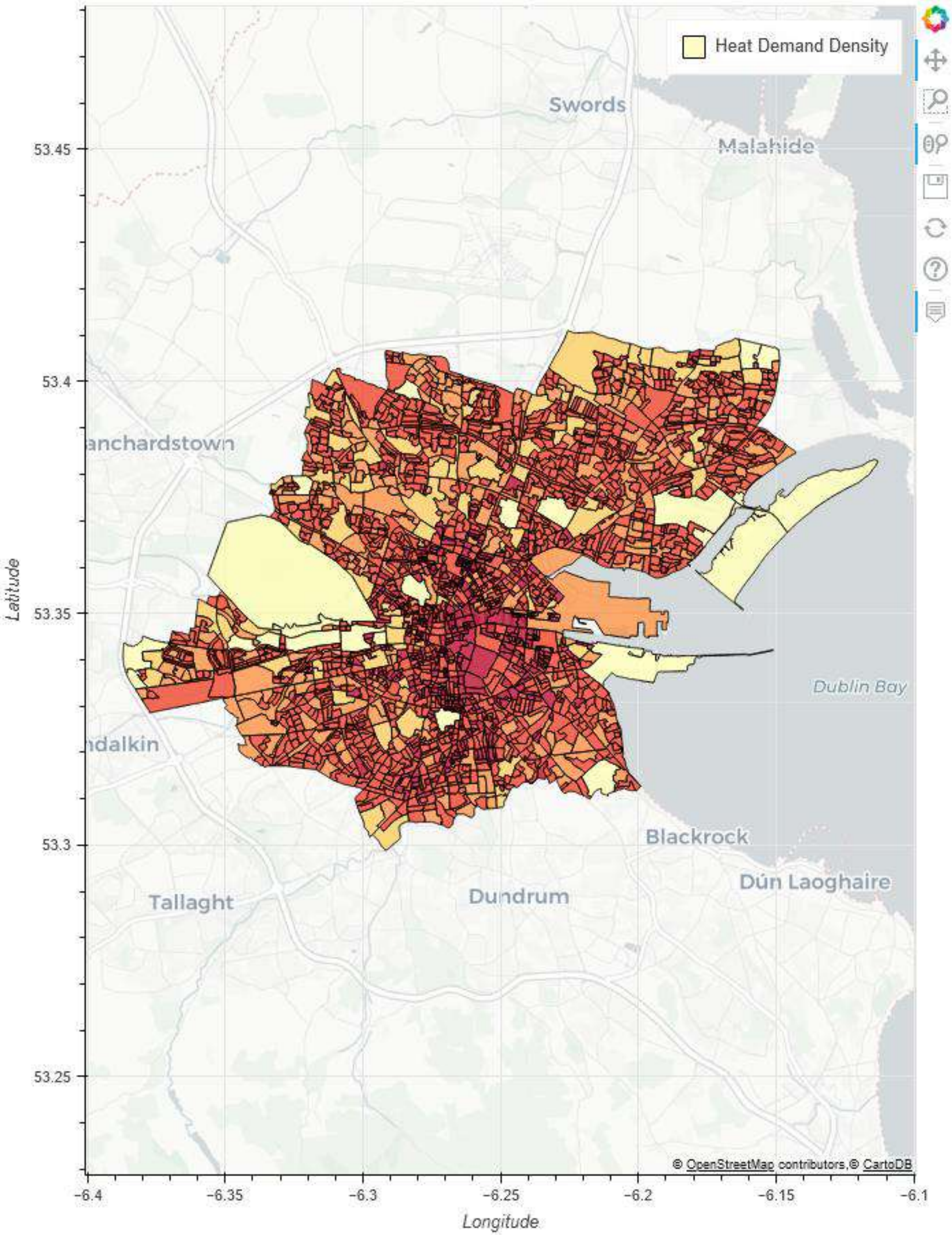
Heat Demand Assessment Methodology

The heat demands calculated for residential, commercial and municipal buildings are discussed in more detail in **Appendix B - Building Sector Methodology.**

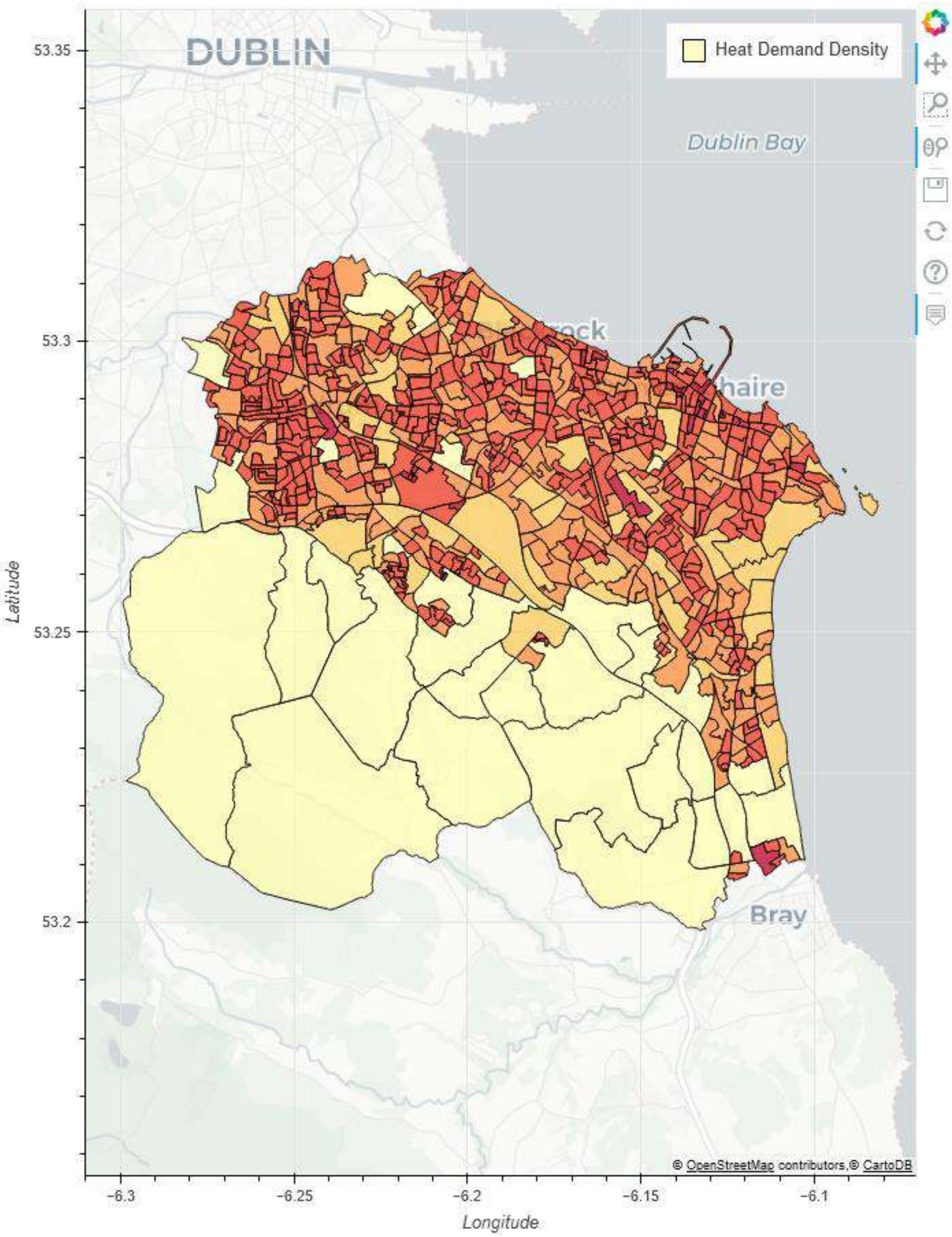
Heat Demand Density Maps

The maps on the next page show the heat demand density in TJ/km² for each CSO small area in the county. This metric is one of the key indicators for DH suitability. An interactive version of these maps is available on the Codema-dev GitHub page[188]. The breakdown of demand categorised as very feasible, feasible, not feasible, etc. can also be found on this webpage. The table below provides indicative figures for DH suitability based on this heat demand density metric alone. The DH vs HP assessment in the next section of this report builds on this analysis and directly compares the two low-carbon heating options based on the cost of carbon abatement. Interestingly the carbon abatement cost analysis shows district heating as a better option for even more of Dublin than the analysis based on demand density alone.

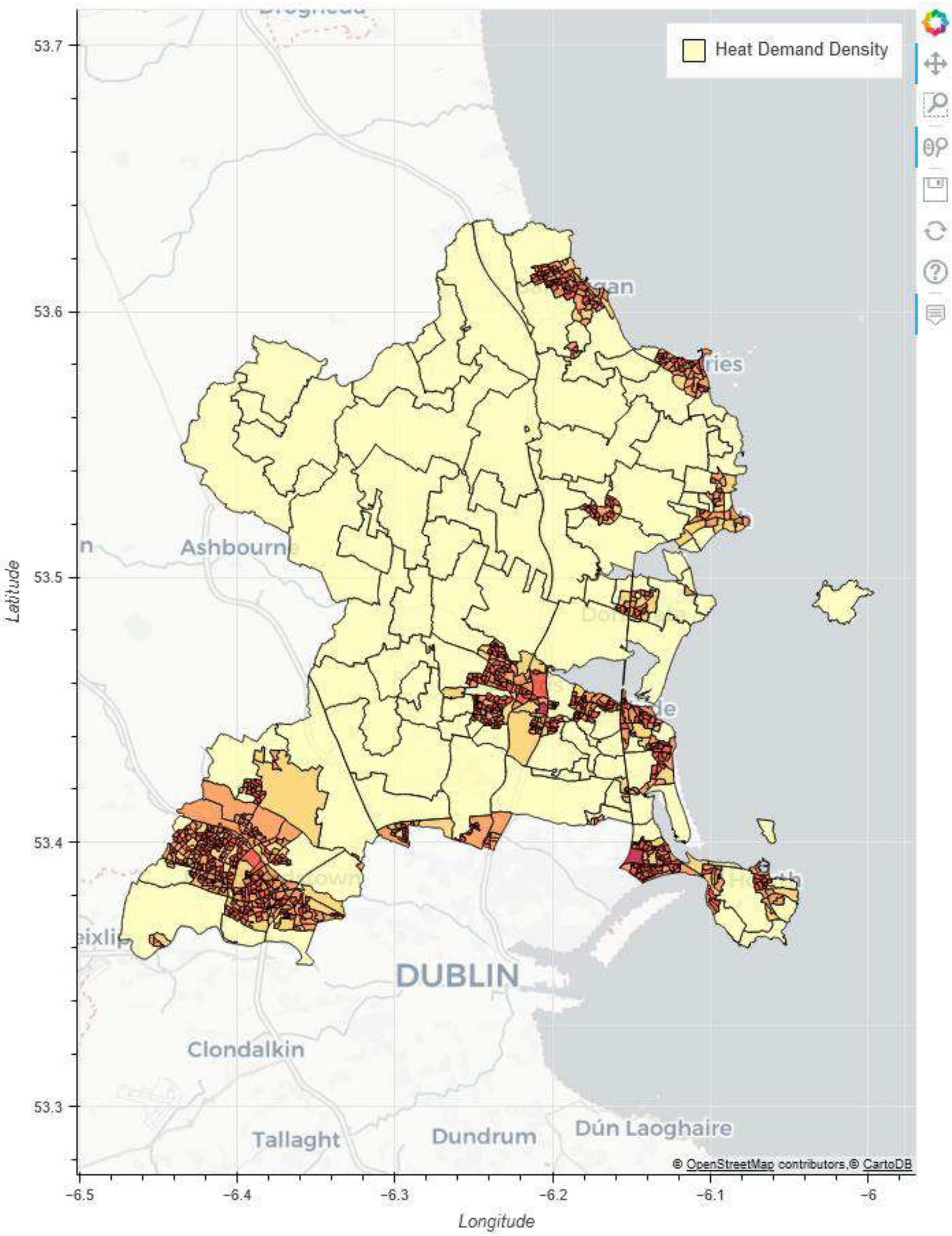
[188] https://codema-dev.github.io/map/district-heating-viability-map-v2/



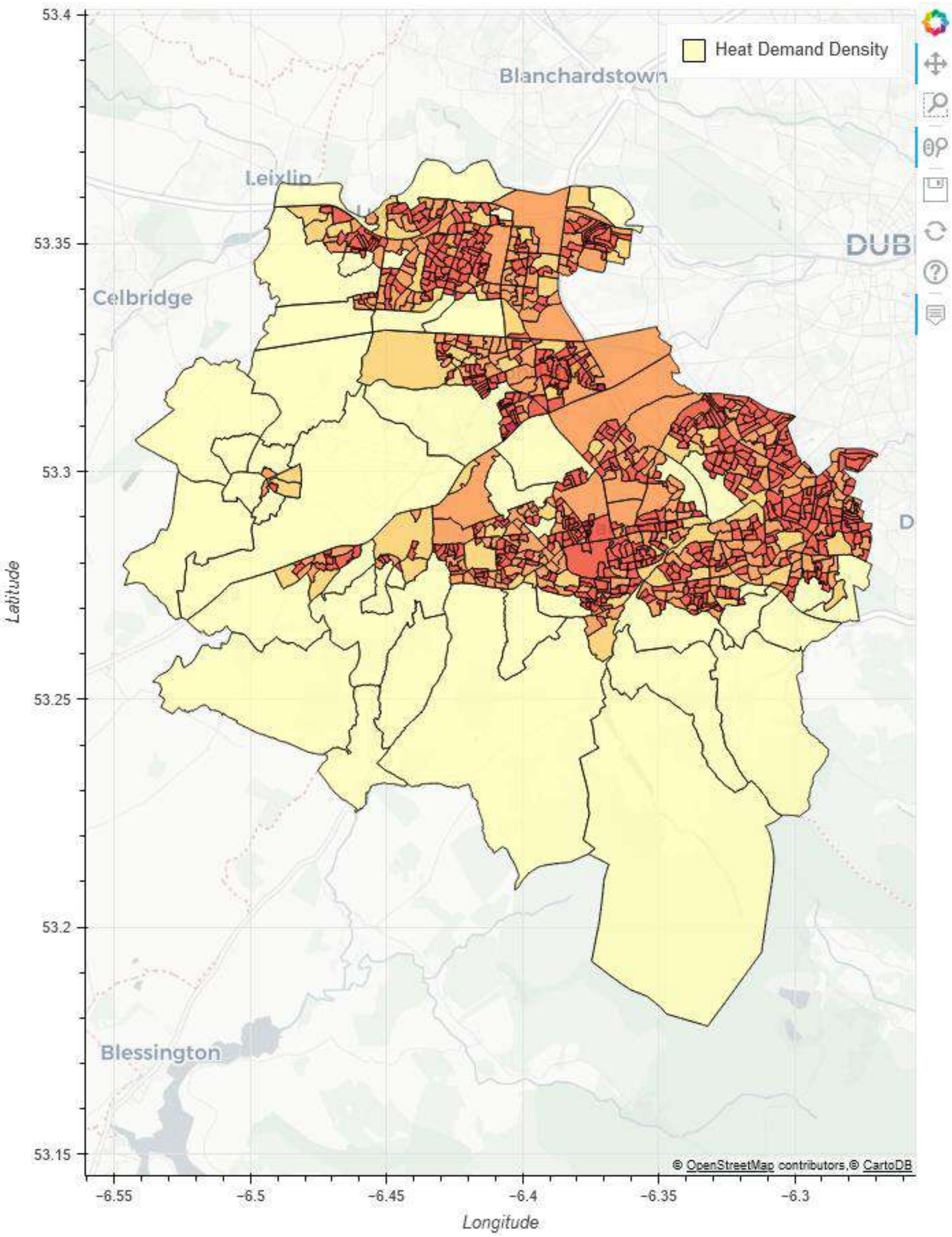
Feasibility	Residential [MWh/year]	Non-Residential [MWh/year]	Total [MWh/year]	Band [TJ/km²year]	% Share [MWh/year]
Not Feasible	23733	7803	31535	<20	0.7
Future Potential	89688	34996	124683	20-50	2.7
Feasible with Supporting Regulation	430562	172766	603327	50-120	13.1
Feasible	2229477	431259	2660736	120-300	57.7
Very Feasible	627162	561711	1188872	>300	25.8



Feasibility	Residential [MWh/year]	Non-Residential [MWh/year]	Total [MWh/year]	Band [TJ/km²year]	% Share [MWh/year]
Not Feasible	59819	11311	71130	<20	3.6
Future Potential	92982	31842	124824	20-50	6.4
Feasible with Supporting Regulation	499936	49750	549686	50-120	28.1
Feasible	930500	124522	1055021	120-300	53.9
Very Feasible	50567	104448	155016	>300	7.9



Feasibility	Residential [MWh/year]	Non-Residential [MWh/year]	Total [MWh/year]	Band [TJ/km²year]	% Share [MWh/year]
Not Feasible	202340	216774	419114	<20	18.7
Future Potential	111750	97646	209396	20-50	9.3
Feasible with Supporting Regulation	493013	205626	698639	50-120	31.1
Feasible	772538	70229	842767	120-300	37.5
Very Feasible	12996	62182	75177	>300	3.3



Feasibility	Residential [MWh/year]	Non-Residential [MWh/year]	Total [MWh/year]	Band [TJ/km²year]	% Share [MWh/year]
Not Feasible	68612	94245	162857	<20	7.6
Future Potential	91650	58127	149777	20-50	6.9
Feasible with Supporting Regulation	420262	317177	737439	50-120	34.2
Feasible	999177	81127	1080305	120-300	50.1
Very Feasible	13797	11785	25582	>300	1.2

Assessment of DH vs Heat Pumps

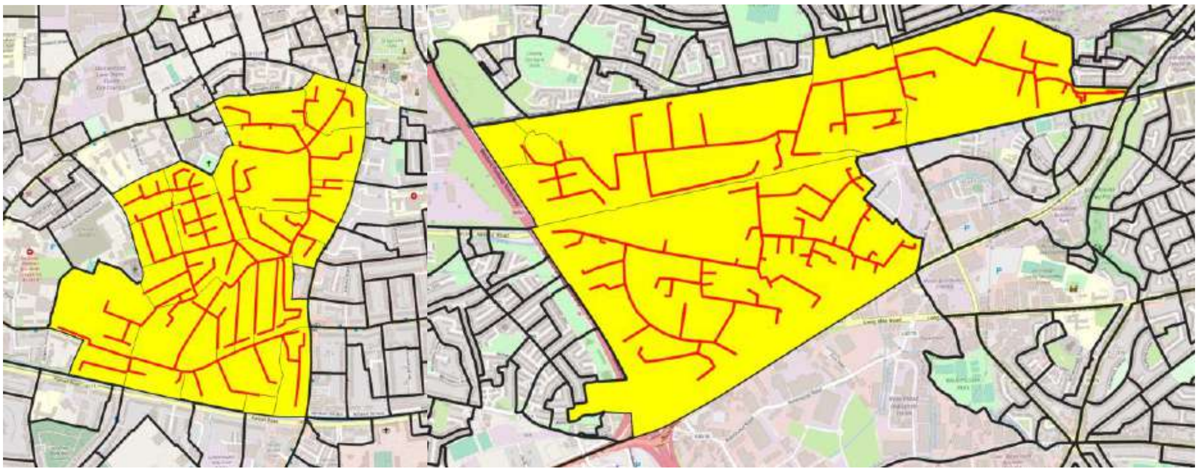
This section of the report sets out how the decarbonisation pathway for heating was determined. This section looked at two main heat decarbonisation strategies; one based on the adoption of district heating networks and the other looking at the widespread adoption of air source heat pumps. This analysis was performed for every CSO small area. The total number of CSO small areas in Dublin is 4,884. The determining factor in choosing one technology over the other was the cost of carbon abatement. The technology with the lowest carbon abatement cost (€/tCO_2 abated) was chosen as the preferred decarbonisation pathway. The cost and carbon abatement figure was calculated based on local conditions within each small area as discussed below.

Heating Cost Calculations

The cost calculation used in determining the cost of abatement for each heat decarbonisation pathway includes the up-front capital investment, an annualised replacement cost based on the equipment lifespan and an indicative operation and maintenance costs.

District Heating Costs

The network length within each small area was determined through the use of random sampling. In this sampling exercise, indicative networks were drawn on multiple areas of a certain urban fabric. An example of the network routes drawn can be seen in the map below in red. The network length was then compared to the road centre line lengths from open street map (OSM). This relationship was then used to estimate the network length required within each small area.



The average DH pipe diameter rounded to the nearest standard pipe size was estimated for each small area based on the linear heat density using the following relationship[189]:

$$Average\ DH\ Pipe\ Diameter\ (mm) = (0.048 * ln(Linear\ Heat\ Density\ in\ MWh\ per\ metre) + 0.063) * 1000$$

It was assumed in this analysis that all pipework was installed in hard dig areas to help ensure that the cost was not being underestimated. In reality, the civil works cost will likely be lower than this as some of the network will run through soft dig areas (green field and brown field areas). Civil works costs in soft dig areas can be 50% lower than in hard dig areas. Avoiding hard dig routes along roads also has the added benefits of reducing traffic disruption and avoiding the likely significant restrictions due to existing utilities in these areas but may require way leaves where the pipe runs through privately-owned land. The pipework was assumed to be bonded steel conti pipework pairs (i.e. not twin pipe) with series 2 insulation. The cost assumed for the mechanical installation of the pipework includes for the supply, delivery, offloading, installation (including allowance for fittings, joints and termination seals) and hydraulic testing (10% non-destructive testing of welds) of the network.

189 https://hre.aau.dk/wp-content/uploads/2018/09/STRATEGO-WP2-Background-Report-6-Mapping-Potenital-for-DHC.pdf

The capital cost of the heat production equipment was estimated based on a representative €/kW figure, which includes the capital cost of the main heating plant, backup heating plant, and auxiliary and automation equipment. The kW used to determine the cost was based on an average diversified peak heat demand for each domestic dwelling plus the diversified peak commercial demand based on the calculated annual heat demand and a typical equivalent run hours for commercial buildings.

The cost of the heat interface units for each domestic building was assumed to be €1,000. For commercial buildings, the heat substation cost was determined based on the average kW rating per commercial building using the graph below.

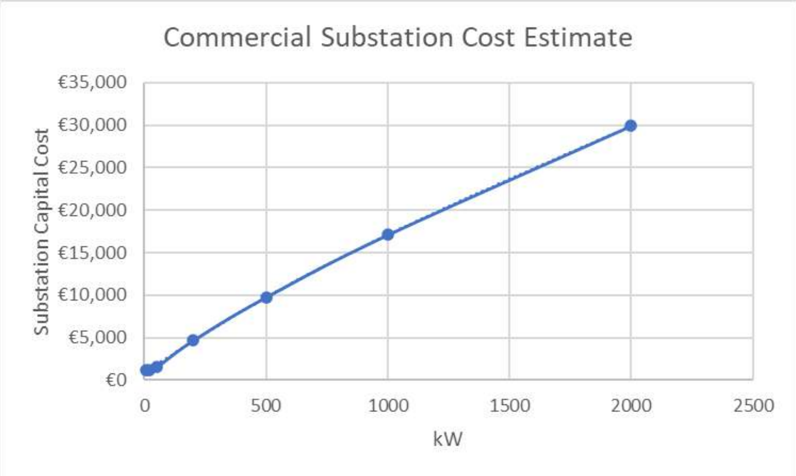


Figure 101: Heat substation cost graph for commercial buildings

Heat Pumps Costs

The capital cost of the heat pump option was calculated using a figure of €1,200/kW thermal output. This figure assumed air source heat pumps (air to water) were fully installed including fittings, buffer tank, new cylinder (existing cylinders are not deemed compatible with efficient heat pump operation due to the relatively small surface area of their coils) and controls, but excluding the heat distribution system. Excluding the distribution system may mean the cost estimate for an efficiently-operating ASHP system may be slightly underestimated in some cases.

It is understood that once heat pumps start to represent a significant proportion of the heat market, the cost of heat pumps will reduce as supply chains improve, installation overheads reduce and the equipment cost itself also reduces. This cost reduction is captured in this analysis through the annualised replacement expenditure (Repex) cost, which assumes a 20% reduction[190] will occur within the first lifecycle of the heat pumps, i.e. before 2036.

Whilst not included in this analysis, it is also worth noting that the floor area consumed by the required hot water cylinder also has a cost associated with it. For a build-to-rent apartment in Dublin, this cost is estimated at €2,350 per dwelling, for example. This cost benefit for DH was excluded as the majority of buildings in Dublin are existing buildings and already have hot water cylinders of a similar footprint installed and are designed in such a way that the floor area freed by removing these units is of limited value.

Heat Pump Grid Upgrade Costs

The installation of heat pumps in homes will also have an impact on the electricity grid which, in certain areas, upgrades will be required to serve these new loads. The cost of these upgrades has been estimated for the LV & MV grid and also for the HV grid using two different approaches.

[190] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/498962/150113_Delta-ee_Final_ASHP_report_DECC.pdf

The LV & MV grid upgrade cost adopted was based on costs from ESB Statement of Charges[191]. For existing homes whose current connection (typically 12kVA) will need to be upgraded (assumed to 16kVA) to service additional load from the heat pump (but also potentially EV charging and greater use of electric cookers). This connection upgrade charge is stated as being €1,539 for a single urban connection. This includes MV network costs but excludes trenching within the boundary of the site. Assuming a power factor of 0.95 for the heat pump load, this translates to a LV & MV upgrade cost of €405/kW$_e$. The additional trenching cost is estimated at €6/m based on typical rates. This trenching cost would apply to all new connections but considering that Dublin consists of predominantly existing buildings and the limited impact of such a low cost, this trenching cost has been excluded from the analysis.

For commercial buildings, the impact of heat pumps on the building's maximum import capacity (MIC) was assessed in order to determine if the HP installation resulted in the building breaking its existing MIC threshold and thus incurring additional cost for falling within a higher MIC band. In the vast majority of cases, it was determined that the addition of a heat pump would not result in the building reaching the next MIC price band, but where it does the cost has been included.

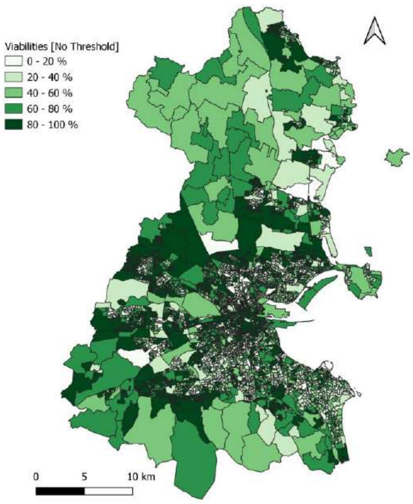
Heat Pump Building Fabric Constraints

One of the main constraints to the adoption of individual building-level heat pumps is the requirement to have a sufficiently energy efficient building that allows the heat pump to supply adequate heat (enough to keep the building at a comfortable temperature) without detrimental effects to the HP's efficiency.

The metric used to assess a building's suitability for heat pumps is known as the Heat Loss Index (HLI). In order for a residential dwelling to be deemed suitable, it requires a HLI of 2 W/K.m^2 floor area or less. The HLI can be defined as the total heat loss (fabric and ventilation losses). Where the HLI is between 2 and 2.3 W/K m^2, in some cases it may not be feasible to upgrade the home further; in this case a HLI of 2.3 can be accepted once the following criteria[192] are satisfied:

- Maximum exposed wall U-value 0.37 W/m^{2}K
- Maximum roof U-value 0.16 W/m^{2}K or 0.25 W/m2K where not accessible (e.g. flat roof or rafters)
- Maximum Window U value 2.8 W/m^{2}K* (and double glazed)
- Maximum Adjusted Infiltration Rate of 0.5 ac/h

The map of heat pump viability (shown on the next page) was created using Codema's synthetic building stock, which maps out the HLI indicators that are less than 2, to create a map of heat pump viability in each small area.



[191] https://www.esbnetworks.ie/docs/default-source/publications/esb-networks-dac-statement-of-charges.pdf
[192] https://www.seai.ie/publications/Technical_Advisor_Role.pdf

Figure 102: Heat pump viability following upgrades

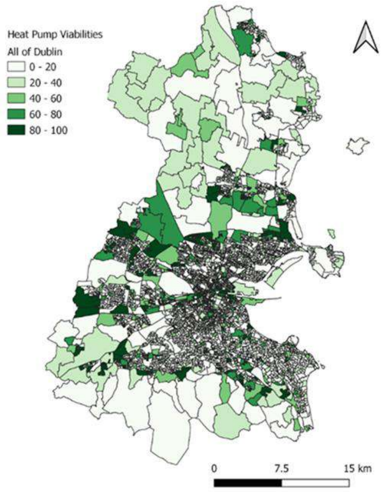


Figure 103: Current Heat Pump Viability in Dublin

Heating Emissions Calculations

The graph below compares the CO_2 emissions outputs of the current predominant heating technology (gas boilers) with the two low-carbon options (DH and HP) from current levels, based on 2019 and on average emission rates for the periods up to 2030 and 2050, respectively. These figures also include equivalent emissions from refrigerant leaks, methane leakage from gas networks and uncombusted fuel, and the warming from NOx emissions. This shows that DH is the lowest emissions technology of the options shown.

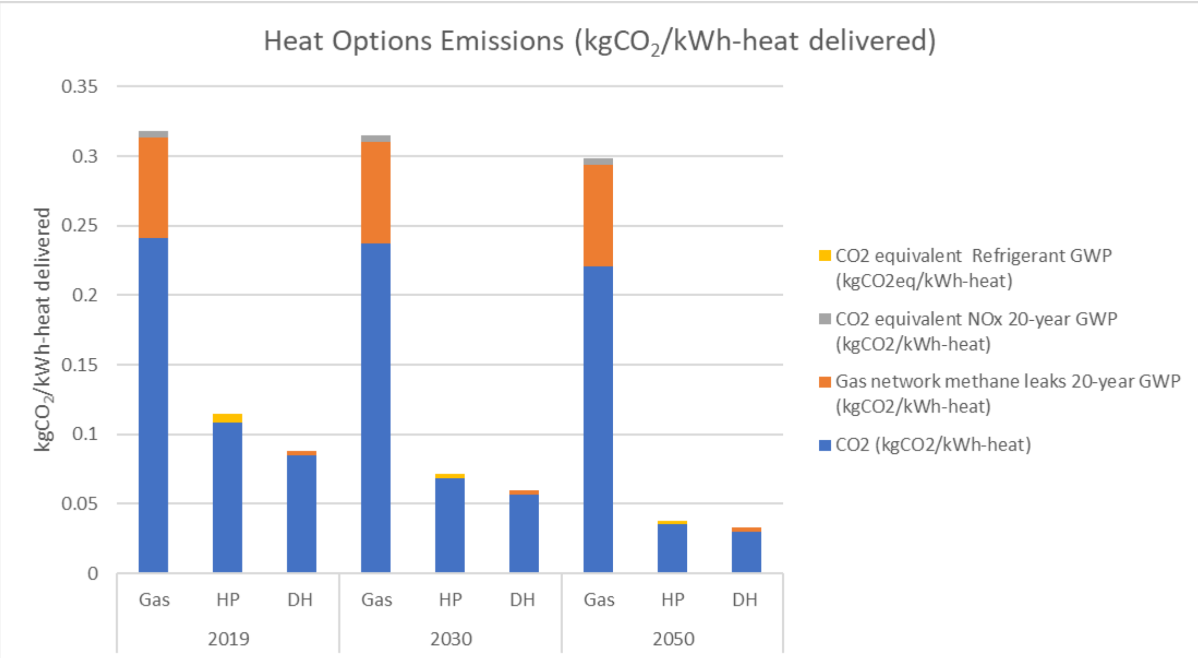


Figure 104: Carbon and equivalent emission per kilowatt hour heat for heat technology options analysed and predominant exiting heating technology in Dublin (gas boilers)

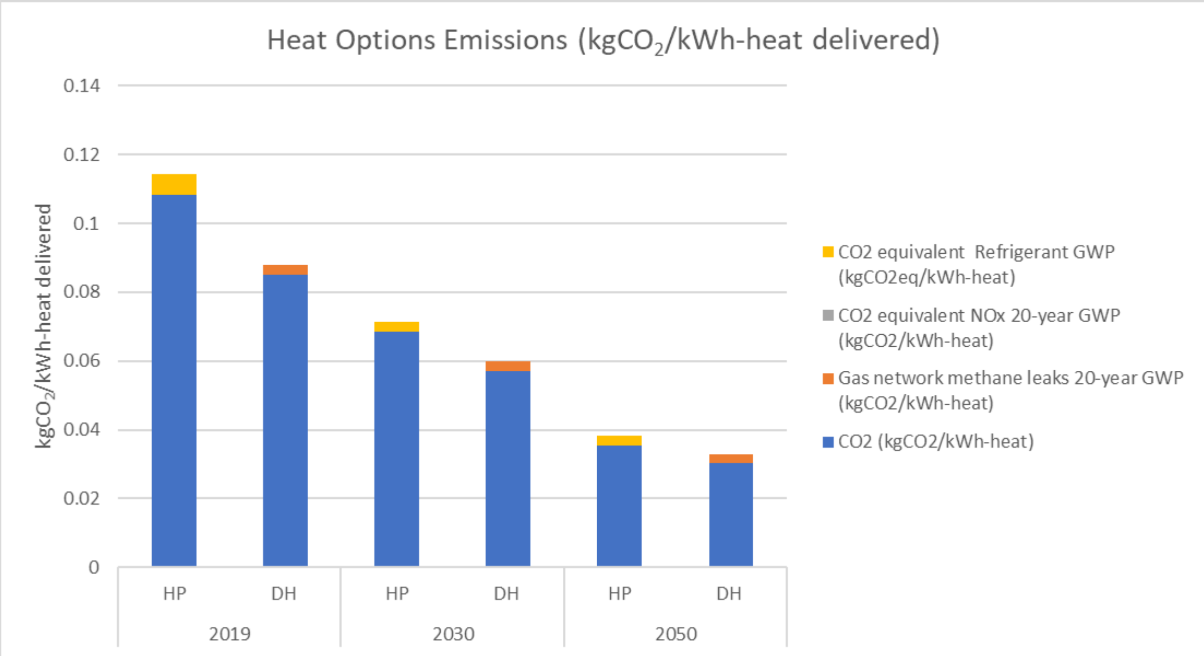


Figure 105: Carbon and equivalent emission per kilowatt hour heat for heat technology options analysed

These emissions figures are used to calculate the emissions savings of adopting either the DH or HP technology for an area. These are then combined with the costs discussed previously to calculate the €/tCO_2 abated figure for each small area.

The graph on the next page below shows the figures and efficiency assumptions used in calculating these emissions outputs. It should be noted that in the case of DH, the efficiency figure is based on an average efficiency of the two DH networks currently being developed in Dublin. The emissions from electricity and gas are adjusted based on expected decarbonisation and renewable targets.

Table 35: Assumption for emissions calculations in the heating sector

	Efficiency	Nox (g/GJ)	Nox (mg/kWh)	PM (g/GJ)	PM (mg/kWh)	CO2 of Fuel (kgCO2/kWh)	2030 CO2 of Fuel (kgCO2/kWh)	2050 CO2 of Fuel (kgCO2/kWh)	CO2 Factors Source	Nox and PM Emissions Source	Nox (mg/kWh-heat)
Gas	85%	32.73	117.8	0.03	0.1	0.2047	0.1990	0.1489	SEAI, CAP 2	EPA	138.6211
Oil (Kerosene)	80%	44.13	158.9	0.31	1.1	0.257	0.257	0.257	SEAI	EPA	198.5848
Direct Elec	100%	0	0.0	0	0.0	0.3245	0.1180	0	Used SEAI	N/A	0
HP	300%	0	0.0	0	0.0	0.3245	0.118	0	Used SEAI	N/A	0
Wood Pellet Boiler	65%	49.8	179.3	22.4	80.6	0.025	0.025	0.025	DEAP	EPA	275.8152
Stove (soft wood)	65%	50	180.0	44	158.4	0.025	0.025	0.025	DEAP	EPA	276.9229
Stove (wet wood)	65%	66	237.6	118	424.8	0.025	0.025	0.025	DEAP	EPA	365.5382
Smokeless Coal	30%	78	280.8	113	406.8	0.3406	0.3406	0.3406	SEAI	EPA	935.9993
Briquettes	30%	144	518.4	120	432.0	0.3559	0.3559	0.3559	SEAI	EPA	1727.999
DH (Based on Curr	460%	0	0.0	0	0.0	0.3245	0.118	0	Used SEAI	N/A	0

The fuel emission figures were based on the decarbonisation trajectory shown in the figure below. The decarbonisation trajectory of gas is based upon a target of 1.6 TWh of green gas by 2030 in the Climate Action Plan. In 2050, the gas network is assumed to reach 11.6 TWh of biomethane injection and have a mix of 20% hydrogen (20% by volume, which equates to 7% by energy content), based on current assumed limitations of the gas networks and existing appliances to transport and burn gas with higher hydrogen concentrations. The carbon emissions factor for electricity up to 2030 are based on analysis of the national electricity production performed by MaREI consistent with achieving 1.5°C and assume a linear reduction to zero by 2050. It should be noted that reducing the consumption of gas increases the potential for greater decarbonisation as green gas like biomethane which has a limit in terms of production levels can represent a higher proportion of a smaller overall gas consumption figure.

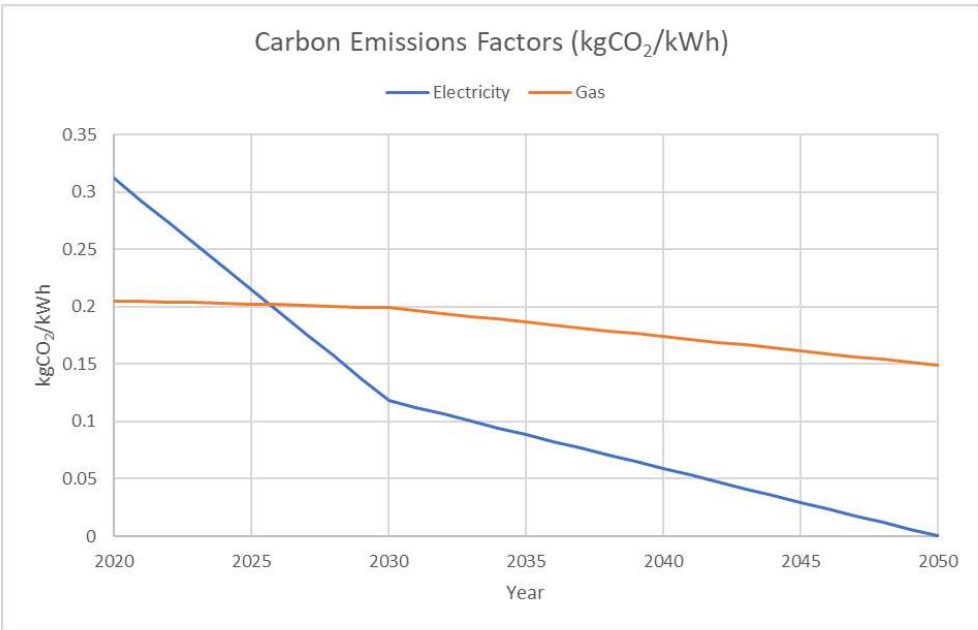


Figure 106: Electricity Grid and Gas Carbon Emission Factors.

Heat Pump Refrigerant Leakage

The CO_2 equivalent emissions from heat pump refrigerant are calculated using a typical refrigerant charge of 2.2kg for both domestic and non-domestic installations and multiplying these by the appropriate median equivalent annual leakage rate[193] as shown in the table below (in the case of domestic dwellings this is 3.48% per annum and for non-domestic it is 3.77% per annum).

Table 36: Heat pump typical refrigerant leakage rates

Installation Type	Frequency of Leakage	Scenario	Leakage Rate for Systems that Leak	Equivalent Annual Leakage Rate[4]
Non-Domestic	8.97%	Low[1]	20%	1.81%
		Central[2]	42%	3.77%
		High[3]	85%	7.63%
Domestic	10.00%	Low[1]	18%	1.82%
		Central[2]	35%	3.48%
		High[3]	100%	10.00%

Notes:
1. 25th Centile Figure
2. Median Figure
3. 75th Centile Figure
4. Derived from the frequency of leakage multiplied by the leakage rate when leakage occurs.

Table 12: Operational Leakage Rates

193 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/303689/Eunomia_-_DECC_Refrigerants_in_Heat_Pumps_Final_Report.pdf

The table on the next page shows the typical refrigerant charge in domestic heat pumps based on their rated thermal output. The refrigerant charge of 2.2kg was used based on the average size of heat pump[194] to calculate the annual kg or refrigerant leaked from individual heat pumps.

Table 37: Typical refrigerant charge in kg for domestic heat pumps

kW_{th} Capacity	kg/kW_{th}	Charge kg
4.32	0.266	1.2
5	0.400	2.0
6	0.367	2.2
8.5	0.259	2.2
8.5	0.259	2.2
11.2	0.268	3.0
11.2	0.268	3.0
14	0.236	3.3
14	0.236	3.3

This resulting average annual kgs of refrigerant were multiplied by a weighted average global warming potential figure of 2,805 $kgCO_2eq/kg$ of refrigerant, which is based on the mix of different refrigerants used in Ireland taken from the national inventory of refrigerants produced by the EPA[195]. A breakdown of this inventory is shown in tonnes of CO_2 equivalent below. It should be noted that the heat pump scenario assumes all heat pumps are at building-level. In the case where multiple buildings are heated by a centralised HP (e.g. DH network), it is assumed that the quantity of refrigerant used in these applications would result in continuous monitoring being in place and the presence of on-site maintenance personnel would reduce the leakage levels to minimal levels. Installations with larger charges are also more cost effective to collect and reuse refrigerant if the HP unit is at its end of life. Systems of this size are also subject to more stringent regulation under the F-gas regulations and hence the refrigerants used would have a far lower GWP.

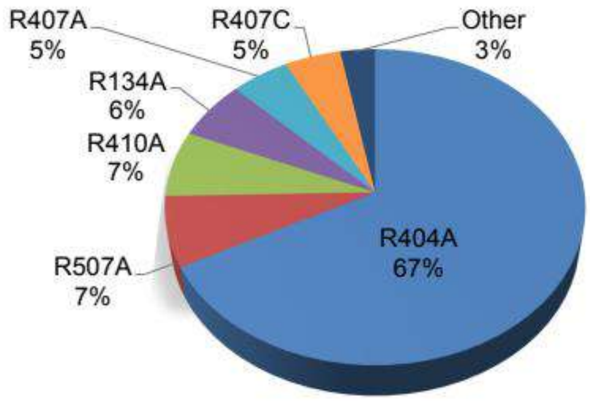


Figure 107: Breakdown of refrigerants in Ireland by CO_2 equivalent

The graph from the EPA on the next page[196] shows the planned phase down schedule of HFC refrigerants. This has been applied to the refrigerant leakage figures in order to estimate the reduction in equivalent CO_2 associated with leaks.

[194] Based on the refrigerant charge figures for the Mitsubishi Ecodan air source heat pump range
[195] https://www.epa.ie/publications/compliance--enforcement/climate-change/Progress_of_Ireland_towards_the_-F-Gas_Phase_Down_November_2017.pdf
[196] https://www.epa.ie/publications/compliance--enforcement/climate-change/6--IRL-Summary-Guide-to-the-HFC-Phase-Down-V1.0.pdf

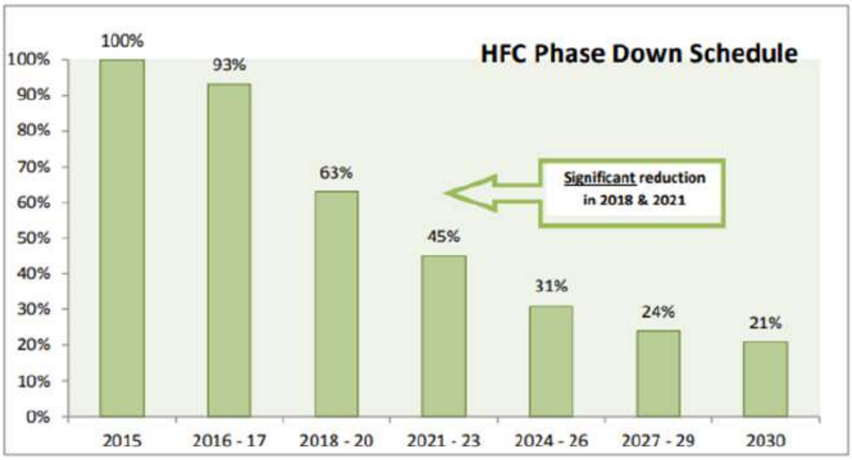


Figure 108: Phase down of HFC refrigerants (source; EPA)

It should be noted that the global warming potential (GWP) was estimated using the 20-year equivalent figures. The reason for choosing this shorter duration figure was due to the timeframes being considered in the analysis (up 2030 and 2050 which translates to roughly a 10 or 30 year time period respectively. This shorter time period also aligns better with Ireland's adoption of five-year carbon budgets for limiting its emissions. The second reason for using these shorter duration GWPs is because even though these elements do not remain in the atmosphere for as long as CO_2 (which remains for centuries rather than decades), their warming effect on the planet is considered irreversible and hence the 20-year GWP more accurately reflects their real impact.

Table 38: CO_2 equivalents for methane (CH_4), NOx and refrigerants

	CO2 equivalents				
	2030 CO2 equivalent CH4 20-year GWP (kgCO2/kWh-heat)	CO2 equivalent NOx 20-year GWP (kgCO2/kWh-heat)	CO2 equivalent Refrigerant GWP (kgCO2eq/kg refrigerant)	2030 CO2 equivalent Refrigerant GWP (kgCO2eq/kg refrigerant)	2050 CO2 equivalent Refrigerant GWP (kgCO2eq/kg refrigerant)
Gas	0.072819557	0.004574495	0	0	0
Oil (Kerosene)		0.0065533	0	0	0
Direct Elec		0	0	0	0
HP		0	1262	589	589
Wood Pellet Boiler		0.0091019	0	0	0
Stove (soft wood)		0.009138454	0	0	0
Stove (wet wood)		0.01206276	0	0	0
Smokeless Coal		0.030887975	0	0	0
Briquettes		0.057023954	0	0	0
DH	0.002831872	0	0	0	0

Gas Boiler Methane Leakage

Gas boilers represent the vast majority of existing heat production units in Dublin (currently 84% of dwellings are heated in this way). The combustion of gas, in addition to generating CO_2 emissions, also releases other greenhouse gases (GHG) such as Nitrogen Oxides (NOx - this is the collective term for oxides of nitrogen which includes NO, NO_2 and N_2O), which is estimated to have a 20-year global warming potential (GWP) that is 33 times greater than CO_2[197]. It should be noted that there is a general lack of consensus regarding the exact GWP of NOx emissions; this is difficult to determine as it varies considerably due to its short lifetime and complex nonlinear chemistry. For this reason, it is currently omitted from the final GHG CO_2 equivalent figures for gas boilers. Unburnt fuel can also be released when full combustion is not achieved and was estimated at 0.001% for this analysis. This also has its own global warming potential as this fuel is predominantly methane (typically 85% - 90%), which has a 20-year GWP that is 72 times greater than CO_2[198]. The gas

[197] Greenhouse effect of NOX, Gerhard Lammel & Hartmut Graßl (1995) https://link.springer.com/article/10.1007/BF02987512

[198] https://www.ipcc.ch/site/assets/uploads/2018/02/ar4-wg1-chapter2-1.pdf

itself also releases methane during its production and distribution. The gas distribution grid in Ireland has a leakage rate of 1.16% based on a five-year average between 2015 and 2019[199] (lower than the EU average of 1.5%) and the gas transmission grid has a leakage rate of 0.31% over the same time period. This leakage rate was checked against typical leakage rates of 520 kg/km and 710kg/km for distribution networks in Canada and the U.S., respectively[200]. Methane leakage from the production of gas was not included in these figures due to lack of available data but could provide a significant uplift in the equivalent CO_2 from methane leakage.

Irish Green Gas Ltd proposes in their 2019 position paper[201] that 11,627 GWh of biomethane could be injected into the gas grid by 2030. The All of Government Climate Action Plan 2021 sets a target of 1,600 GWh by 2030 as shown in the figure below. The inclusion of greater quantities of biomethane in the gas grid would reduce the carbon associated with burning gas but it also should be noted that the biomethane potential would not be able to fully decarbonise the gas system on its own.

Renewable Gas sources	Potential Volumes by 2030	% accessible	Estimated production of Renewable Gas by 2030 (GWh/yr)
Domestic & Commercial Organic Waste	2 Million t ~ 2,000 GWh[16]	92%	1,855
Agricultural manures	2,778 GWh	19%	539
Additional grass (above livestock demand)	28,100 to 54,798 GWh	32% / 16%	8,894
Rotation / Catch Crops	Unknown		339
Total			**11,627**

Figure 109: Biomethane potential from agriculture by 2030 (source: Irish Green Gas Ltd)

Green Hydrogen

Green hydrogen (H2) is hydrogen produced by an electrolyser which uses renewable electricity to split water into hydrogen and oxygen. This green hydrogen can be used in the future to replace grey H_2 (produced using fossil gas through steam methane reformation), which is used predominantly as an ingredient in industrial processes. Green hydrogen can also potentially be used as a green fuel to produce power when renewable electricity from wind or solar is not available or to fuel heavy transport.

Codema believes green hydrogen should only be supported for use in certain applications where the heat supply cannot already be supplied more efficiently and more cost-effectively through renewable and waste heat sources (e.g. through district heating and heat pumps). The use cases where green hydrogen may be supported include industry (where it is used as a feedstock), shipping, long-haul aviation, and seasonal power storage. Figure 110 on the next page shows the ranking of the potential use cases for green hydrogen, with A-rated uses being the most likely to be viable and G-rated the least likely. This figure also outlines how green hydrogen is highly unlikely to be viable for domestic or commercial heating, which covers the majority of heat demand in this analysis.

[199] https://www.gasnetworks.ie/corporate/gas-regulation/regulatory-publications/GNI-Systems-Performance-Report-2019.pdf

[200] https://www.ipcc-nggip.iges.or.jp/public/gp/bgp/2_6_Fugitive_Emissions_from_Oil_and_Natural_Gas.pdf
[201] https://assets.gov.ie/75966/723d0bdd-e3b5-4254-9741-3ed73e92e11c.pdf

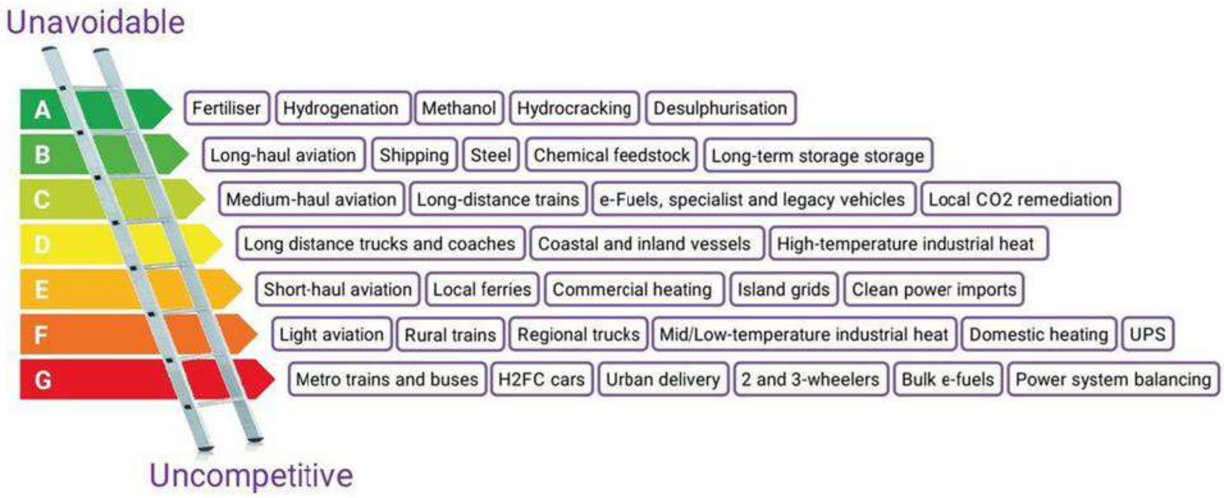


Figure 110: Hydrogen Ladder Ranking Potential Viable Uses of Green Hydrogen (Source: Liebrich Associates)

In recent times, the potential to use existing gas networks to transport green hydrogen (hydrogen produced by electrolysis using green electricity) has been discussed as a possible solution for decarbonising space heating and hot water preparation (<100°C). There are a number of factors that will not make this possible in the short to medium term and makes adopting in the long term challenging. The reason for Codema's position on green hydrogen when it comes to lower temperature heating is that better alternatives already exist for providing heat at this temperature, which are not subject to the same uncertainties around viability that green hydrogen is. Some of these uncertainties which make green hydrogen adoption challenging include:

- The need to avoid lock-in risk: Investing in infrastructure that is based on polluting imported fossil fuels for which significant decarbonisation is extremely unlikely to occur in the short or medium term. Whilst existing infrastructure can accommodate small proportions of H_2, the maximum proportion of H_2 that can be accommodated without issues by volume is 20%. It is worth noting that the by volume percentage differs significantly from the delivered energy proportion due to the difference in energy density between gas and H_2 at the same pressure (i.e. in the same pipe). In the case where fossil gas has 20% of H_2 blended in, this actually translates to a 13% reduction in energy capacity of the pipework with H_2 only providing 7% of the energy delivered. To increase the proportion of H_2 beyond 20%, replacement of pipework, compressors, valves and fittings, boilers, meters and safety sensors would likely be required.

- Suitability of existing pipework for transporting H_2: High pressure steel pipework (>7bar[202]) which represents approximately 4.5% of the gas grid in Dublin is vulnerable to Hydrogen embrittlement (where H_2 diffuses into surface flaws in the pipework, reducing ductility[203]) which causes cracking and failure of the pipe network, valves and fittings (the location of all fittings may not always be apparent in infrastructure that is buried underground). High pressures are believed to increase the likelihood of these failures and hence high-pressure steel networks are not considered suitable for transporting H_2. Older, lower pressure pipework may also be constructed from steel or iron and may also be prone to hydrogen embrittlement if the gas pressure is high enough; this likelihood is reduced somewhat if mild steel is used for the pipework.

Table 39: Breakdown of gas network infrastructure by construction material and pressure rating

[202] https://www.gasnetworks.ie/home/gas-meter/meter-services/Safety-Advice-for-Working-in-the-Vicinity-of-Natural-Gas-Pipeline.pdf

[203] Conversion of the UK gas system to transport hydrogen, Paul E .Dodd et al.

	HP (metres)	MP (metres)	LP (metres)	Total Length (m)
Polyethelene	0	2,015,406	3,367,718	5,383,124
Steel	255,795	48,680	4,278	308,753
Cast Iron	0	0	71	71
Ductile Iron	0	0	1	1
Total length by Pressure	255,795	2,064,085	3,372,067	

	HP (metres)	MP (metres)	LP (metres)
Polyethelene	0.0%	35.4%	59.2%
Steel	4.5%	0.9%	0.1%
Cast Iron	0.0%	0.0%	0.0%
Ductile Iron	0.0%	0.0%	0.0%

- While hydrogen has more energy per weight than fossil gas, it has a lower energy per mole. This would result in the pressure in the gas network to be increased threefold to provide the same energy capacity and hence increase the likelihood of pipe failure caused by embrittlement. This required increase in compression also means that a threefold increase in compressors resulting in increased energy/electricity used to compress the gas would be required as well as ensuring pressure ratings of all pipework is not exceeded to avoid critical network failure.

- Suitability of Polyethylene pipework (used for pipes carrying fossil gas in pipelines less than 7bar pressure[204]) for transporting H_2: Polyethylene pipes are not prone to H_2 embrittlement in the same way that steel pipes are but PE pipes are more porous than steel pipes. These hydrogen-porous pipes represent 95% of the gas network in Dublin. The porosity of such pipes may also be exacerbated by the molecular size of hydrogen molecules - hydrogen is the smallest size molecule that exists, and hence is one which diffuses easily through materials. This can create problems in terms of safety particularly when it comes to elements within buildings but also creates another possible issue in that the Hydrogen itself has a global warming potential estimated with 95% certainty to be between 0 and 9.8 times greater than CO_2 with a central value of 4.3 over a 100-year time horizon based on best available research[205]. It should be noted however that the research on the GWP of H_2 is limited but this early research indicates that while it will likely have an effect on global warming, this will be relatively small. A permeation coefficient of 2.10-17 Nm3.m-1.s-1.Pa-1 for PE membranes when transporting pure Hydrogen has been quoted in report investigating Poly Pipes for Distributing Mixtures of Hydrogen and Natural Gas[206].

- Safety is again a concern due to H_2 being odourless and the difficulty in attaching an odour to a gas which cannot be detected with current sensors installed in boilers. This presents a significant safety issue as H_2 is an explosive gas with a much higher flame rate than fossil gas.

- Converting electricity to H_2 is about 60 - 70% efficient; converting H_2 to heat is about 90% efficient giving an overall electricity-to-heat conversion efficiency of approximately 60% even when excluding leaks from the pipe network. Alternative heating methods have far higher efficiency. For example, the current large-scale DH networks in Dublin have an average efficiency of 460% (almost eight times more efficient than using hydrogen boilers).

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204 https://www.gasnetworks.ie/home/gas-meter/meter-services/Safety-Advice-for-Working-in-the-Vicinity-of-Natural-Gas-Pipeline.pdf

205 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/760538/Hydrogen_atmospheric_impact_report.pdf

206 https://www.researchgate.net/publication/48693261_Polymer_Pipes_for_Distributing_Mixtures_of_Hydrogen_and_Natural_Gas_Evolution_of_their_Transport_and_Mechanical_Properties_after_an_Ageing_under_an_Hydrogen_Environment

- If H_2 is to be used for combustion in hydrogen boilers then their NOx emissions will need to be considered. Assuming flame combustion rather than catalytic combustion, burning hydrogen can result in NOx emission up to six times higher than fossil gas boilers. NOx do not directly affect Earth's radiative balance, but they catalyse tropospheric O3 formation[207] through a sequence of reactions GWP of 7 - 10 over a 100-year horizon (30 - 33 over a 20-year horizon)[208]. NOx is also a main cause of poor air quality which impacts people's health.

- Green H_2 production requires green electricity to be supplied at a low price point. The two main factors which make H_2 financially viable are in conflict with each other, these are (1) the low cost green electricity (available during low demand times) and (2) high utilisation of the electrolyser which produces the green hydrogen to pay off its large upfront cost. Further research is required to determine whether the required levels of each can be achieved simultaneously to produce cost-effective green hydrogen.

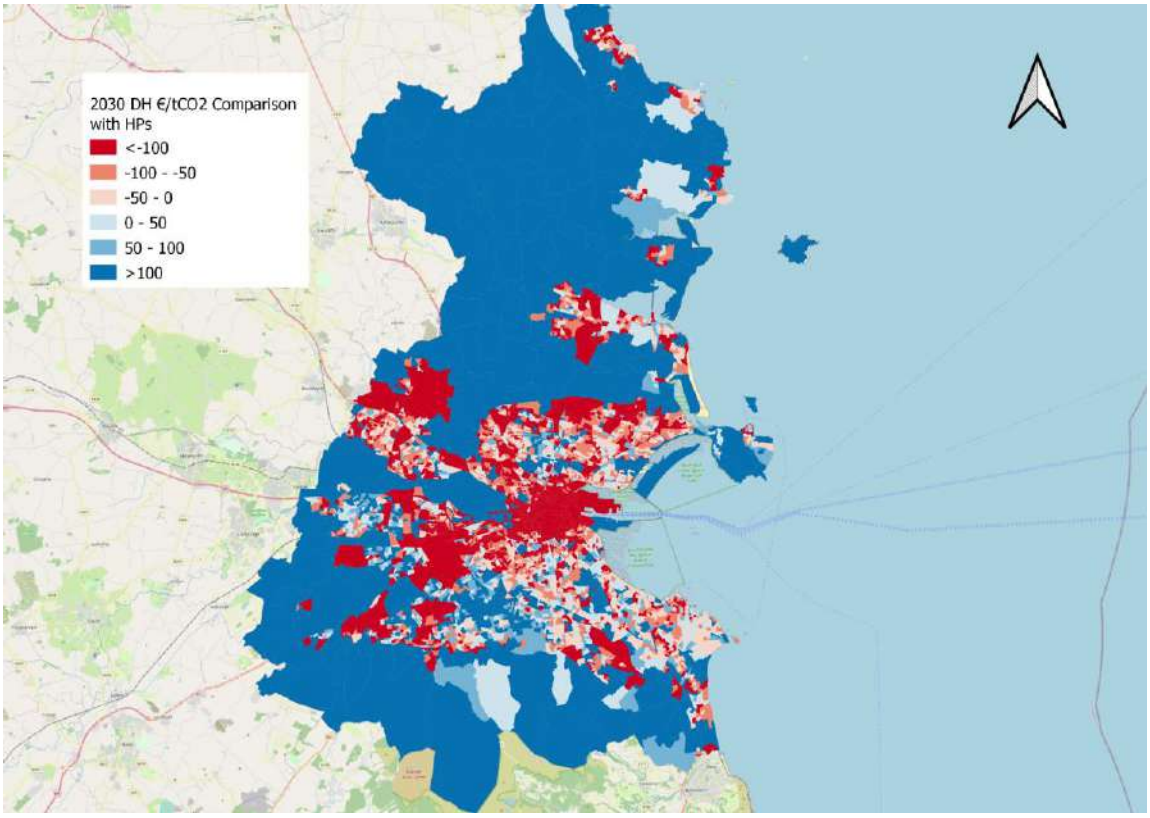
Heating Pathway

This section shows the results of the above analysis. The map below shows the preferred heat decarbonisation option for each small area based on the above analysis and resulting €/tCO_2 abatement cost over the period up to 2030 and 2050. This analysis includes savings from both CO_2 emissions (combusting fuels, consuming electricity) and CO_2 equivalent emissions (methane leaks, refrigerant leaks, NOx emissions). The costs included in this analysis include capital expenditure, replacement expenditure (annualised based on the technologies' expected lifespan) and maintenance costs. The particulate matter (PM) emissions from combustion heating systems which have an impact on local air quality and citizen health is translated into a health impact cost in the Socio-Economic Impact chapter.

It should be noted that for the purpose of this analysis it is assumed that DH heat price to customers is equal to the counterfactual (boilers and heat pump heat prices). This is a conservative estimate as in reality, the DH heat price is likely to be 5 - 10% lower than the alternative heating technology. Unlike HPs, DH can operate efficiently without the need for building fabric upgrades. However, building fabric upgrades have been assumed for both scenarios in line with a "fabric first" approach to deliver energy efficient buildings within the region. The fabric upgrades were adopted to reach threshold u-values on the three main building fabric elements (external walls, windows and roofs).

The figure on the next page shows the areas most suited to each technology up to 2030. The areas coloured blue are most suited to heat pumps and the areas coloured red are most suited to district heating. The darker the colour the most suited that area is to either technology.

[207] https://www.ipcc.ch/site/assets/uploads/2018/03/TAR-04.pdf
[208] Greenhouse effect of NOX by Gerhard Lammel & Hartmut Graßl https://link.springer.com/article/10.1007/BF02987512



By 2030, district heating represents the best option for 7.43 TWh of heat demand (74% of total demand in Dublin) in terms of cost-effective decarbonisation, which would save 1,442.8 ktCO_2 in the year 2030. However, like other technologies, the supply chain needs to be developed in order to deliver on this potential. The current national government target of 2.7 TWh by 2030 reflects the supply chain growth experienced by other countries when they first began adopting DH in the 1970s. As Dublin is more advanced in the planning and development of DH systems, it is fair to assume that the majority of this target will be met by Dublin and so this was used as a reasonable interim regional target for 2030. This 2.7TWh would save 502.0ktCO_2 in carbon emissions and save 172.8kT$CO^2_{eq.}$ in equivalent emissions in the year 2030. The map below shows the areas where DH could be first adopted (i.e. is most cost-effective) to reach this 2.7TWh target.

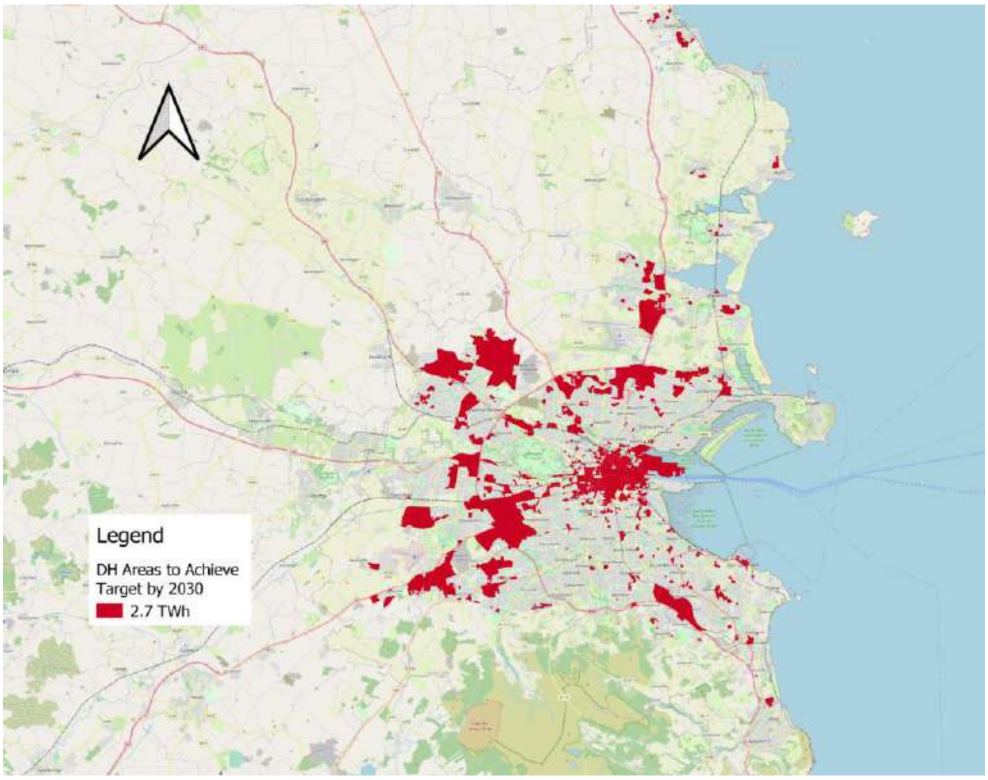
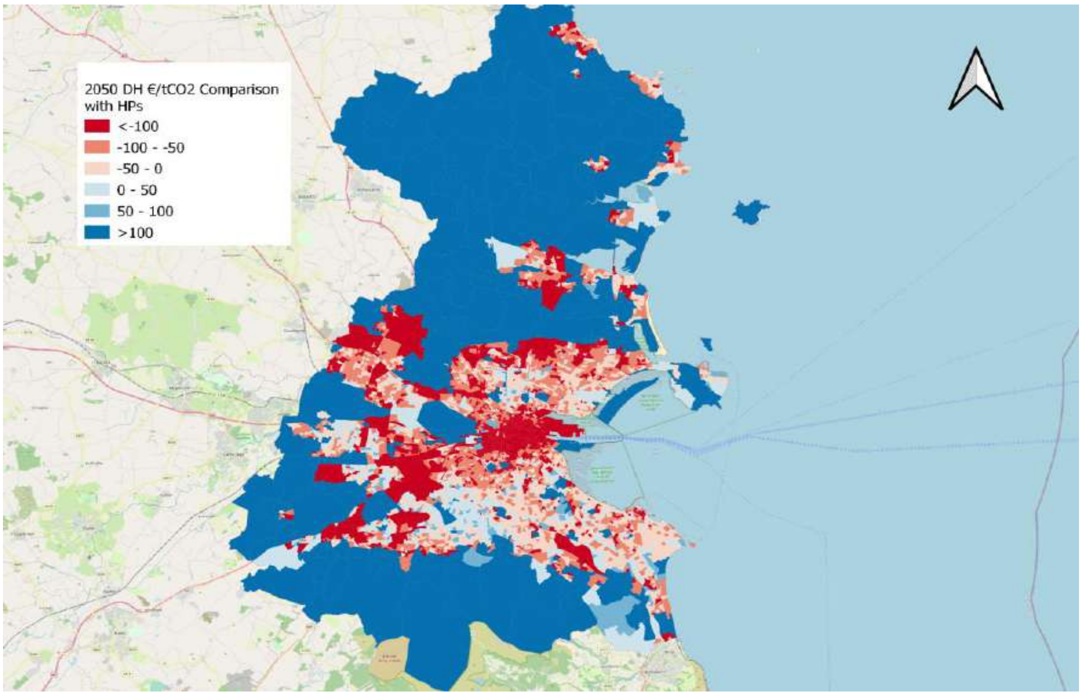


Figure 111: Map of Areas to Have DH to Achieve 2030 Target of 2.7TWh

The 2.7TWh target for 2030 would require 376.1km of distribution pipework and 784.5km of customer connections, estimated to cost €980.4 million. The total capital cost of achieving this target is estimated at €1.1 billion with the majority of this investment staying within the local economy. This would create the equivalent of 2,281 direct local jobs each year for this period to 2030.

The figure below shows the areas most suited to each technology up to 2050. The areas coloured blue are most suited to heat pumps and the areas coloured red are most suited to district heating. The darker the colour the most suited that area is to either technology. It can be seen from this map that the areas suited to DH have increased over the period 2030 to 2050. The main reason for this is that the up-front capital investment in the network infrastructure is recouped over a longer period in this scenario. It is worth noting that this effect will continue beyond 2050 making DH an even better solution over time.



By 2050 district heating represents the best option for 9.06TWh of heat demand (87% of Dublin's total heat demand) in terms of cost-effective decarbonisation. By 2050 it is assumed that the required supply chain is in place to deliver on the full DH potential outlined. This would save 1,550.1ktCO_2 in carbon emissions and save 617.6kTCO_2eq. in equivalent emissions in the year 2050.

This DH roll out optimised to 2050 would require 2,421.8km of distribution pipework and 4,209.5km of customer connections estimated to cost €5.7 billion. The total capital cost of achieving this target is estimated at €7.7 billion with the majority of this investment staying within the local economy. This would create the equivalent of 4,354 direct local jobs per year for the period 2021 to 2050.

Heat pumps represent the best option for 93,362 buildings (6,845 commercial and 86,517 residential dwellings) in 2030 saving 503.9ktCO2 and 165ktCO2 equivalent. However, this drops to 78,128 buildings (5,600 commercial premises and 72,528 residential dwellings) by 2050 due to the increased competitiveness of the DH networks over a longer time span (due to the network lifespan being in excess of 50 years compared with a 15 year lifespan for an individual heat pump). The total capital cost of installing 78,128 heat pumps (excluding the building fabric upgrades) is €1.2 billion. This would create the equivalent of 382 direct local jobs per year[209] for the period up to 2050. These individual heat pump installations would cover 1.27 TWh of heat demand in 2050 and save 233.1 ktCO2 and 80.9 ktCO2 equivalents.

In order to avoid double counting of carbon savings, fabric upgrade savings are calculated based on the assumption that the aforementioned technology adoptions take place - full adoption of both DH and HPs by 2050 and the interim targets met by 2030 (i.e. 2.7TWh DH and 78,128 heat pumps). These figures are based on 317,577 homes undertaking some level of retrofit by 2030 (166,966 external wall retrofits, 18,360 roof retrofits and 314,533 window retrofits). This would save 206.3ktCO_2 in 2030 but once the other heating technologies are adopted by 2050 this saving drops to zero. The reason for this drop is that the only fuel used by the heating systems outlined in this analysis would be electricity to drive the pumps for collecting waste heat, geothermal heat, etc. or for heat pump compressors where heat pumps are required to increase water temperatures. It should be noted that the additional benefits of increased comfort and efficiency delivered by retrofitting are included in line with the "fabric first" approach adopted by the government. In the case of DH, the efficiency gains of this fabric first approach are not as pronounced and therefore shallower or no retrofitting may be required in these areas but should be assessed on a case-by-case basis.

[209] Assuming the 30% of the cost for install stays within the local economy

Appendix D - Electricity Sector Methodology

Potential Low-Carbon Electricity for the Dublin Region

The potential for renewable electricity generation in Dublin is investigated in this section of the report. In order to determine the cost of developing this potential, the following levelised cost of energy (LCOE) figures were used. This is also sometimes referred to as the life-cycle cost (LCC). The LCOE is a way of comparing generator technologies and considers the capital and operational costs of the technology. The LCOE figures[210] used in this assessment are set out below. This has been combined with the carbon saving potential of these technologies when compared with the current generation mix to give a carbon abatement cost as shown in the table below.

From this table we can see that utility scale solar PV (-101.1 €/tCO_2) represents the most cost-effective means of decarbonising the electricity sector followed by onshore wind (-94€/CO_2) and then offshore wind (-55€/tCO2). Rooftop solar (147€/tCO2) provides the least value for money in terms of carbon abatement in the electricity sector.

Technology	€/MWh	€/tCO_2 Abated
Offshore Wind	65.6	-55.0
Onshore Wind	52.9	-94.0
Utility-Scale Solar PV	50.6	-101.1
Closed-Cycle Gas Turbine	97.8	N/A
Open-Cycle Gas Turbine @ 500 hours	228.9	N/A
Open-Cycle Gas Turbine @ 2000 hours	157.6	N/A
Building-Integrated Solar PV	131.1	147.0
Current Generation Mix (2019)	83.4	N/A

The renewable electricity generation potential for 2030 and 2050 are set out in the Table below. It is clear that offshore represents the biggest opportunity for Dublin. The Curtailment that has been avoided due to the usable storage provided by district heating and EVs is also shown in a separate row here.

Technology	GWh		tCO_2 Saved	
	2030	2050	2030	2050
Utility-Scale Solar PV	854	1,057	277,124	343,036
Onshore Wind	130	325	42,163	105,572
Offshore Wind	5,241	13,124	1,700,768	4,258,600
Building-Integrated Solar PV	84	270	27,237	87,763
Curtailment Assumed Avoided by EV+DH	462	2,421	149,892	785,551
Total	**6,309**	**14,776**	**2,047,292**	**4,794,972**

The assumptions around curtailment/dispatch down for each generating technology is as follows. Curtailment has been assumed to be zero for solar generation as it produces electricity during the day when electricity demand is at its highest. For wind generation curtailment of 8.6% was assumed for 2030. This figure represents the national 3-year average curtailment between 2018 and 2020 in Ireland. It is assumed that for Dublin this level of wind curtailment could be sustained to 2030 due to the significant electrical load even in off-peak demand periods and the proximity of the demands to the generators and the significant existing capacity of the grid in the area to transport the electricity generated to these demands. For 2050 curtailment was assumed at 18% this is based on the assumed high capacity factor of offshore wind as the main renewable electricity generation in the Dublin region and the proximity of significant base load demand to these sources. Further research into the curtailment/dispatch down of large wind generators (particularly offshore wind).

210

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/911817/electricity-generation-cost-report-2020.pdf

These figures assume that the energy that would be lost due to curtailment has been avoided through the use of two main storage options DH and EVs. The DH networks thermal storage can enable GWh of electricity to be stored as usable heat for homes and businesses and EVs can enable GWh of electricity to be stored to provide mobility or be fed back to the grid in a vehicle to grid (V2G) connection in 2050.

Solar Photovoltaics

Photovoltaic (PV) cells convert solar radiation directly into DC electricity. PV uses energy from light to create electricity; when light shines on a PV cell, it creates an electric field across the layers causing electricity to flow. Individual PV cells only provide a small amount of electricity, so they are generally grouped together into a module for convenience. PV is generally more suited to areas where the electricity generated can supply a nearby load, and the energy loss and costs associated with transmission and distribution are avoided.

The potential generation capacity of building-integrated PV across Dublin rooftops, along with adopting utility-scale solar PV (USSPV) on all areas of land deemed suitable has been calculated at 270 GWh and 1,057 GWh[211], respectively. If all these projects were implemented this would translate to a total CO_2 saving of 430,800 tonnes per year.

Utility Scale Solar PV Potential
Codema has analysed the CO_2 reduction potential of both building integrated and utility-scale solar PV (USSPV) panels in the County. For USSPV sites, there is a combination of both technical and spatial constraints that must be considered in order for a site to be deemed suitable. These include:

- Areas within 1km of grid infrastructure - shorter cable runs to this electrical infrastructure will reduce any extra cost or environmental impact associated with this connection
- Location where topography and visual screening could be used to mitigate the potential visual impact of the array - visual screening is highly site-specific and can be remedied with sensitive landscaping practices, therefore no site was deemed unsuitable due to poor screening or topography at this stage
- Areas with low biodiversity value - Codema has taken this to mean any areas which do not have a high biodiversity value (e.g. SPAs, SACs, NHAs and proposed NHAs as discussed in the Councils' Biodiversity Plans)
- Open spaces with minimal shading
- Areas that do not have a northward slope (slope with aspect within 45° of due north) of greater than 10° to the horizontal - Codema generated slope and aspect maps using a digital elevation model (DEM)

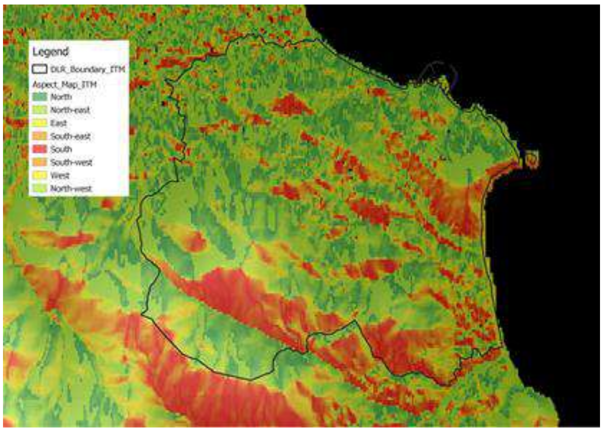


Figure 112: Digital elevation model created by Codema to identify suitable topography for USSPV

[211] Assuming a SID success rate of 75% for utility-scale solar projects

- Areas not within 30m of woodland to avoid issues with shading and falling leaves or within 30m of road or rail to avoid dust and debris - this is a general assumption that can be adjusted for specific sites as part of a more detailed feasibility study
- The typical minimum size for a viable industrial-scale PV farm is 5 MW. A farm of this size would require a land area of approximately 10 hectares - Codema removed any land parcel smaller than 10ha that is not directly adjacent to any other sites (which together would sum to 10ha)
- Areas not within 100m of existing roads or rail lines to avoid potential glint and glare concerns

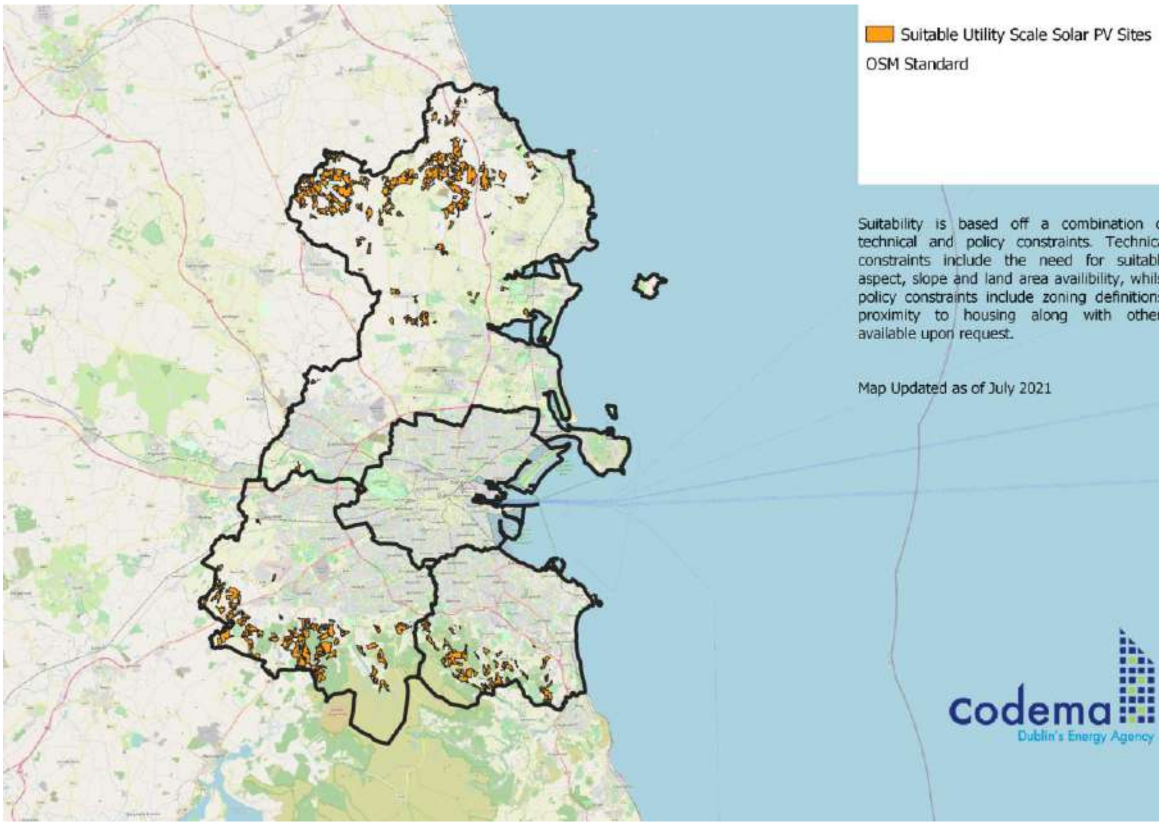


Figure 113: Suitable sites for utility-scale solar PV

Building Integrated Solar PV Potential
A key advantage of PV is the potential to be integrated into the fabric of the building (in many cases the roof). Maintenance costs would be predicted to be low, requiring occasional cleaning and maintaining/replacing tiles and inverters as necessary. There would be no noise or land take associated with roof-mounted PV.

Building integrated solar PV panels also have limits put upon them based on the electrical grid infrastructure. This is in part due to the greater diversity in demand for which the grid was designed and the lower diversity in electricity production when looking at PV generation, where peak production occurs at pretty much the same time across all units (i.e. peak irradiance occurs concurrently across all PV panels within a given area). This is reflected in the ESB Networks Asset Management Analysis,[212] which states “that the network can currently accommodate widespread micro-generation penetration at levels up to 3kWp (rural) and 4kWp (urban). At lower levels of penetration, 6kWp/11kWp can be provided and may result in some levels of reinforcement. At higher penetration levels of 6kWp/11kWp, or at greater than 11kWp, an individual system study is required for each connection assessing associated work and costs”. Codema performed a high-level check on the electricity production results based on the recommended kW per dwelling

[212] ESB Networks Asset Management. 2019. Assessment of potential implications for the distribution network of defined higher penetrations of distributed generators.

(4kWp) figures for widespread adoption on rooftop PV and found that these limits would not be reached. It is worth noting that this was not a detailed analysis looking at individual minipillar capacities as this information was not available at the time of writing this report.

In the case of building integrated solar PV, the following indicators can be used to identify sites which are most suitable for such an installation and formed the basis for analysing the building-integrated PV potential in Dublin:

- Sufficient space to install the array - allowing for access and occasional maintenance
- Areas with minimal overshading from adjacent buildings, trees, etc.
- Area for installation that is secure - to help protect the array from damage
- On-site demand profile matches production and demand is less intermittent (e.g. commercial buildings as shown in the daily profile figure below) - this maximises the use of the electricity generated on-site and reduces the need for battery storage or spill back onto the electrical grid which is of lower monetary value
- Buildings with year-round electricity consumption (including summer)
- The orientation and pitch of the roof is important when considering roof-mounted installations - flat roofs or those with a southern aspect are preferred
- The structural integrity of the building - is it sufficient to handle the additional dead loads and wind loads of a solar array?
- Installation of a solar array is permissible, e.g. the building is not a protected structure

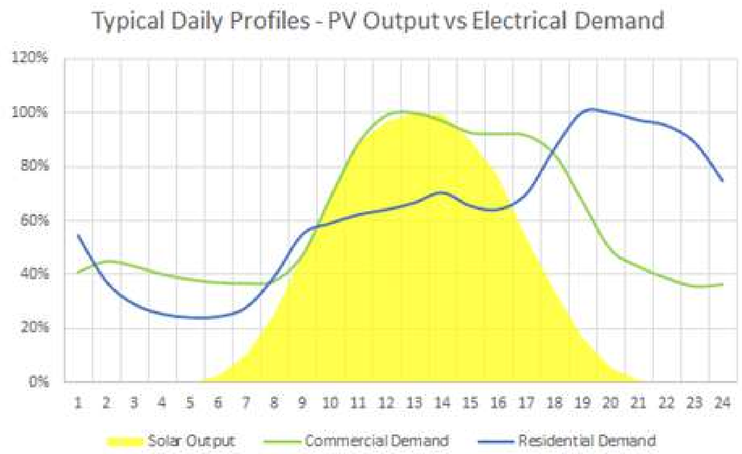


Figure 114: Daily electrical demand and PV generation profiles

The potential for solar PV integration on buildings was estimated using land classifications from the European Environment Agency Urban Atlas (which did not overlap with OSI vegetation maps, or land areas identified as suitable for utility-scale solar PV). Urban Atlas data was used as it provides a more detailed breakdown of land uses in urban areas. Roof areas for each land classification were estimated by random sampling roof areas in multiple locations (of one hectare) within the same land class. This gave an average percentage of urban fabric land area covered by roofs of approximately 20%. Of the locations surveyed, 10% of this roof space was deemed suitable for PV, i.e. it did not experience shading, was not already occupied by roof-mounted plant, had a flat roof or in the case of a pitched roof, had a general southerly orientation (within 90° of due south).

The potential generation capacity of building-integrated PV across Dublin rooftops has been calculated at 270 GWh. If all these projects were implemented this would translate to a total CO_2 saving of 87,763 tonnes per year.

Wind Energy

Wind energy is produced primarily through wind turbines, which harness the wind to provide mechanical power to a generator to produce electricity. Wind turbines are a key technology in the decarbonisation of the electricity sector and are by far the largest renewable electricity generating method in Ireland, representing approximately 36% of total electricity generation[213]. The national target for renewable electricity is to have 80% renewables by 2030. It is envisaged that wind power will continue to play a leading role in meeting this target.

Onshore Wind Potential

Codema has identified onshore wind strategic energy zones in accordance with RPO 7.35 of the RSES and has estimated the potential CO_2 reductions of installing wind turbines in these areas.

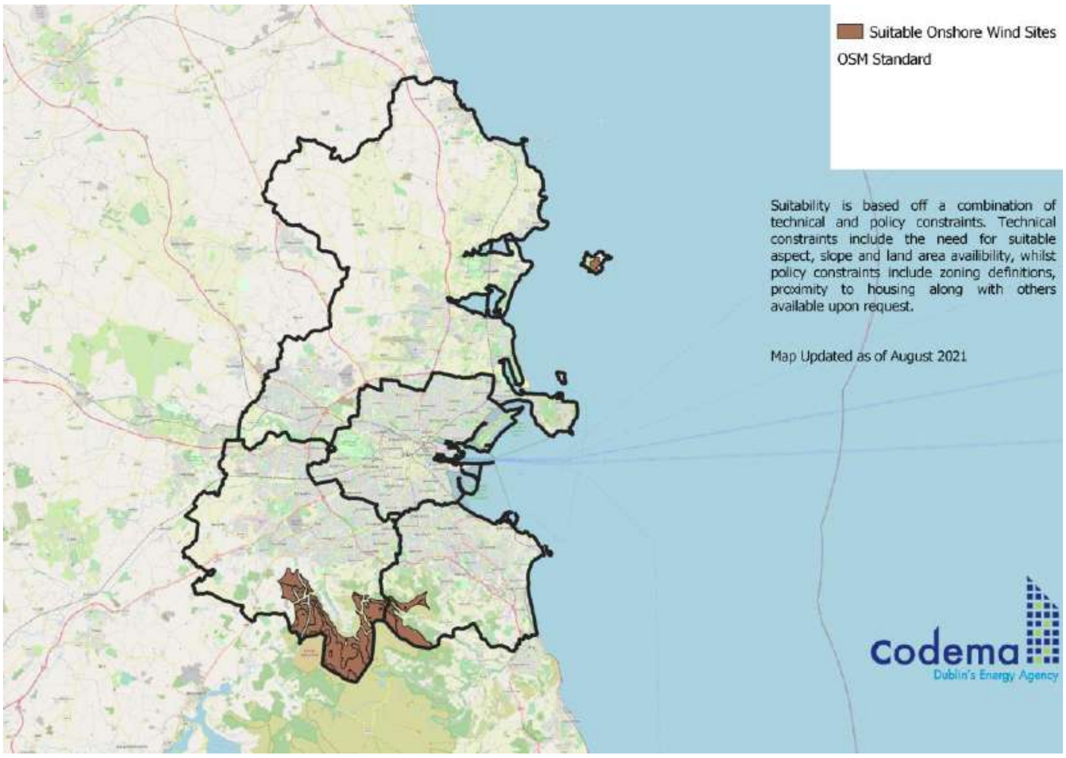


Figure 115: Suitable sites for onshore wind

Similar to the USSPV sites, a combination of both technical and spatial constraints existed for the analysis of potential onshore wind sites. These are as follows:

- Not within 5km of a large town or city - Dublin City Council administrative boundary taken as the city boundary, large town defined as town centres from the County Development Plan 2016 zoning maps
- Not within 2km of the perimeter of a small town - continuous and discontinuous urban fabric layers of high density were used to define the boundary of small town equivalent
- Not located in an environmentally sensitive area (e.g. SAC, SPA, NHA)
- Not located within woodland areas or within 200m of woodland areas
- Located in areas with optimal wind speeds (greater than 8m/s assuming a 75m hub height)
- Not within 500m of any residential area or within a minimum distance of four times the turbine height from any home - locations of individual homes were not known at the time of writing this report but potential to use the Council's geodirectory data could be used to model this more accurately, if available.

Based on recommended minimum spacing between turbines of 3.5 times the rotor diameter in the crosswind direction and seven times the rotor diameter in the prevailing downwind direction, it is estimated that the sites across the Dublin mountains could accommodate 87 3.5MW wind turbines. These sites show the best promise as a wind energy Strategic Energy Zone (SEZ). Assuming a capacity factor of 35%, these sites could produce 510 gigawatt hours (GWh) of electricity

[213] Based on 2020 figures

per year, which provides a carbon saving of 165,603 tCO_2 per year. It should be noted that this capacity factor is higher than the average seen by current wind turbine installations, which have an average of 27% over the last four years[214]. The assumed higher capacity factor is due to new wind farms utilising the latest technology to achieve higher capacity factors.

Offshore Wind Potential

Despite the higher wind speeds from the Atlantic Ocean in the West of Ireland, the east is still very suitable for offshore wind development, due to its shallow sand banks,which can greatly ease foundation construction and maintenance. Offshore wind represents the biggest opportunity in terms of renewable electricity production. This is highlighted by the size and quantity of offshore wind farms in early planning that hope to be among the first offshore wind farms developed in Ireland for years. In this study, Codema has estimated the electricity generation potential of the proposed offshore wind farms, which look to bring this renewable energy ashore via sites within Dublin's county boundary.

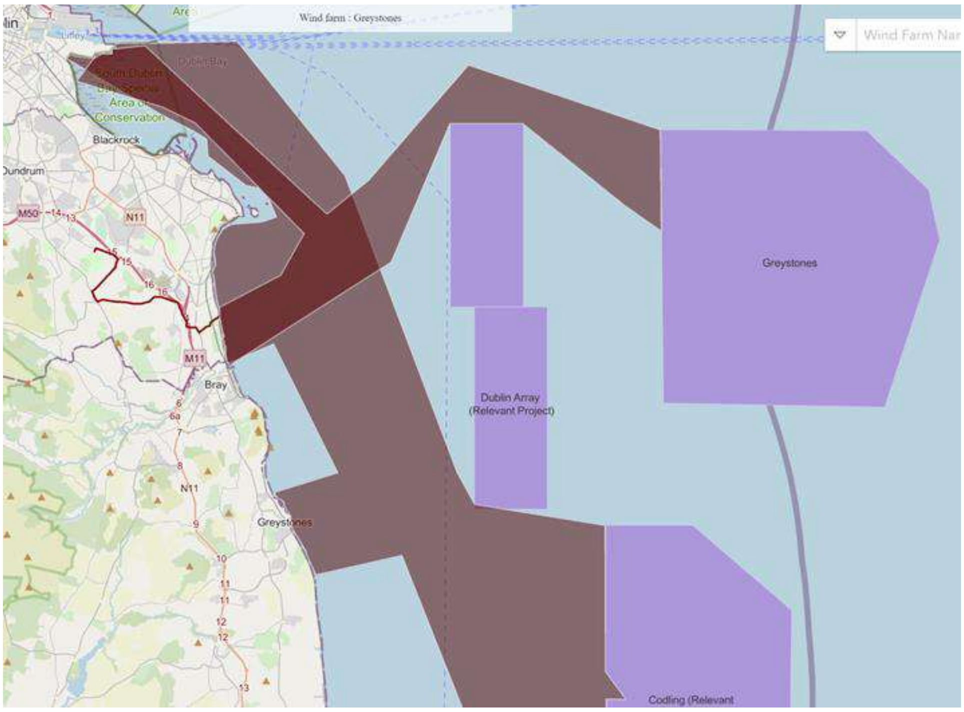


Figure 116: Offshore Wind Potential Map Source: https://www.4coffshore.com/offshorewind/

There are five offshore wind farms whose green electricity was identified as being likely to come to shore within Dublin's county boundary. These are listed with their planned upper and lower boundary installed capacities in the table below.

Table 40: Planned Lower and Upper Bound Capacities for Offshore Wind Farms

Name	**Lower Bound Capacity (MW)**	**Upper Bound Capacity (MW)**
Greystones	1000	1000
Dublin Array	600	900
Codling	900	1500
North Irish Sea Array	500	500

214 http://www.eirgridgroup.com/site-files/library/EirGrid/Annual-Renewable-Constraint-and-Curtailment-Report-2020.pdf

Ballymore Point	800	800
Totals	**3800**	**4700**

In order to convert these capacities into potential annual generation in Gigawatt hours (GWh), a number of assumptions were made in relation to the capacity factor assumed for offshore wind generation (assumed at 50%[215]). Attrition and Strategic Infrastructure Development (SID) success rates were assumed to be in line with historical onshore rates[216] for lower bound potential to 2030. Lower attrition rates and higher SID success rates based on requested policy improvement by IWEA for onshore wind projects were assumed for the upper bound generation potential for 2050. These rates are shown in the table below.

Table 41: Attrition and strategic infrastructure development success rates used for determining wind generation potential (source: IWEA)

Wind	Lower	Upper
Attrition Rate	33%	15%
SID Success Rate	38%	75%

These were applied to the upper bound capacities in table 41 to give the results seen in the table below. The potential for offshore wind in 2030 was calculated at 5,241 GWh of renewable electricity, saving 1,700 ktCO_2 per year. It should also be noted that the generation potential of this offshore wind asset is likely to reduce as a result of dispatch down (i.e. electricity that could potentially be generated is not captured due to grid constraints and curtailment). Based on three-year average (2018 - 2020) dispatch down figures from EirGrid this would be of the order of 8.6% of generation (364 GWh). Potential exists to reduce curtailment through the electrification of other sectors and pushing non-critical demands to these periods when demand is low but renewable electricity generation may be high, e.g. night-time. In this analysis we can see that the DH networks can provide adequate storage for this curtailed electricity and use it to provide zero carbon heating to homes and businesses.

Electricity Demand

The figure on the next page shows the electricity demand for the residential (left hand side) and commercial (right hand side) sectors.

[215] https://www.iea.org/reports/offshore-wind-outlook-2019
[216] https://windenergyireland.com/images/files/iwea-building-onshore-wind-report-lr.pdf

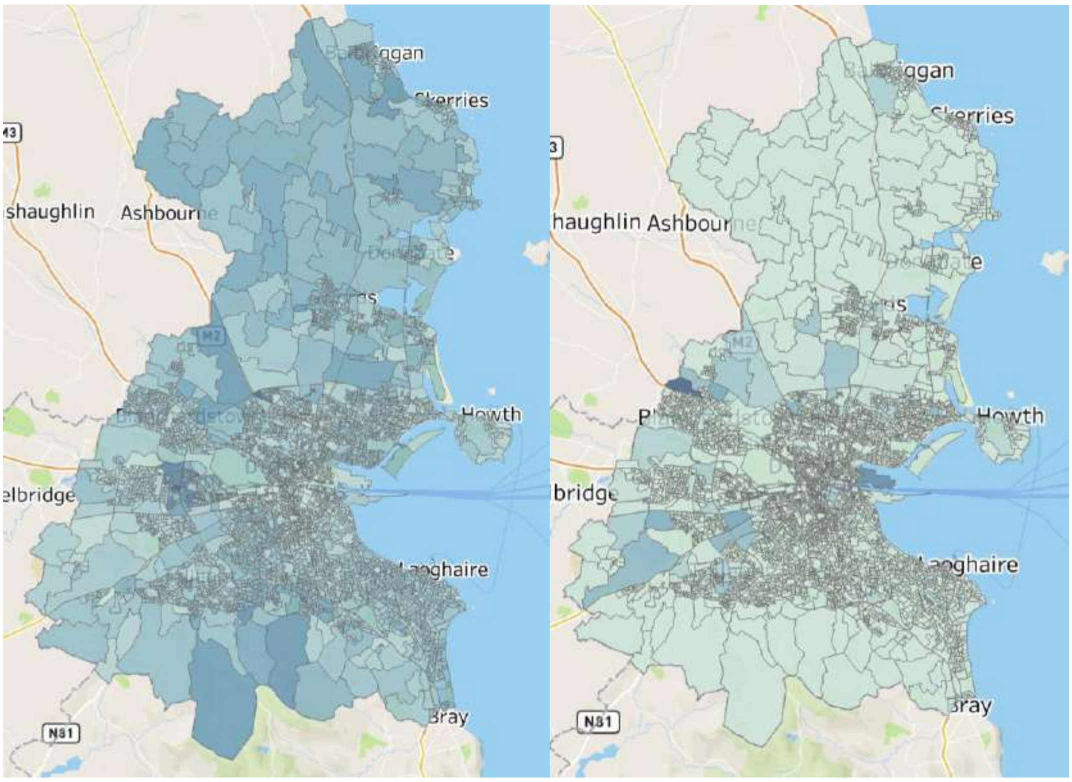


Figure 117: Residential and commercial electricity demand maps for Dublin

Data Centre Demand

The global demand for data storage and cloud computing continues to increase following the COVID-19 pandemic. Dublin has become one of the largest data centre hubs in Europe in recent years due to its temperate climate (reduced cooling load), dark fibre connectivity, power availability and reliability, political stability, 'pro-business' economy, attractive tax rates, and educated English-speaking workforce. These data centres represent a significant electricity demand on the grid now (4,310GWh) and into the future, and therefore are an important consideration when considering capacity constraints and the production of low-carbon electricity for further electrification of the energy sectors. Benchmarking was originally undertaken; however, it was found that placing a single value on the consumption of data centres simply wasn't representative enough. Bitpower was kind enough to offer its assistance in the form of an annual report they compiled on the electricity consumption of data centres in Ireland. One issue here, however, is that the results received only indicate the electricity consumption of the data centres and not the overall energy demand of the site, so these values are therefore excluded in the total county demand profile.

These data centres are predominantly situated on the outskirts of the M50, and due to their proximity, this places additional demand constraints on the grid. This is particularly notable when viewing the overall demand map for Dublin at a small area level, when it can be noted how consumption peaks in the west in areas containing these data centres.

It should be noted that data centres are not all the same, and they can be split into several categories:

- Hyperscale data centers are household name corporations that build and operate their own data facilities to their own specifications. For security and competitive reasons, their internal architecture and design are kept mostly private. Hyperscale data operations in Ireland represent about 300 MW of connected power, increasing to 760 MW over the next seven years (Bitpower, Ireland's Data Hosting Industry 2017).
- Co-location data centres provide managed facilities for partial use by third parties, and are often useful to attract international customers to Ireland initially on a trial basis before committing to the construction of a full hyperscale data centre. This was the case when Microsoft and Google initially came to Ireland, and five of the top nine big co-location providers operating in Europe have an Irish presence.

- Private data centres also exist and are constructed for a specific type of operation, such as telecoms operators, financial transaction processing companies, and computer graphics specialists. These loads are significantly smaller than their counterparts.

Precise information on data centre available capacities is difficult to obtain. Bitpower summarises these demands and the total connected data centres on a quarterly basis. However, spatially assigning these loads can prove difficult. Relating the 2018 demands provided at an individual level to 2021 involved computing the mean capacity applied for by new developments, summing these loads and adding them to existing demands. This method naturally is subject to notable error bounds, and should be revisited regularly in the coming years to account for recent developments.

Future demand estimates for data centres were carried out following discussions with EirGrid. This is done by taking a percentage of their total utilisation capacity, relative to a specific year. For 2018, Bitpower suggests that 42.5% of data centre loads are being utilised, with 55% by 2020 and EirGrid estimated 90% by 2030.

Bitpower group data centres into key areas (these could potentially be targeted for future DH developments where in close proximity to areas with high heat demand density). These areas are listed below and can be seen in Figure 118.

- Dublin North East (Clonshaugh)
- Dublin North West (Ballycoolin)
- County Meath (Clonee)
- Dublin South West (including Grange Castle and Profile Park)
- Dublin City (including Tallaght, Parkwest, and CityWest)

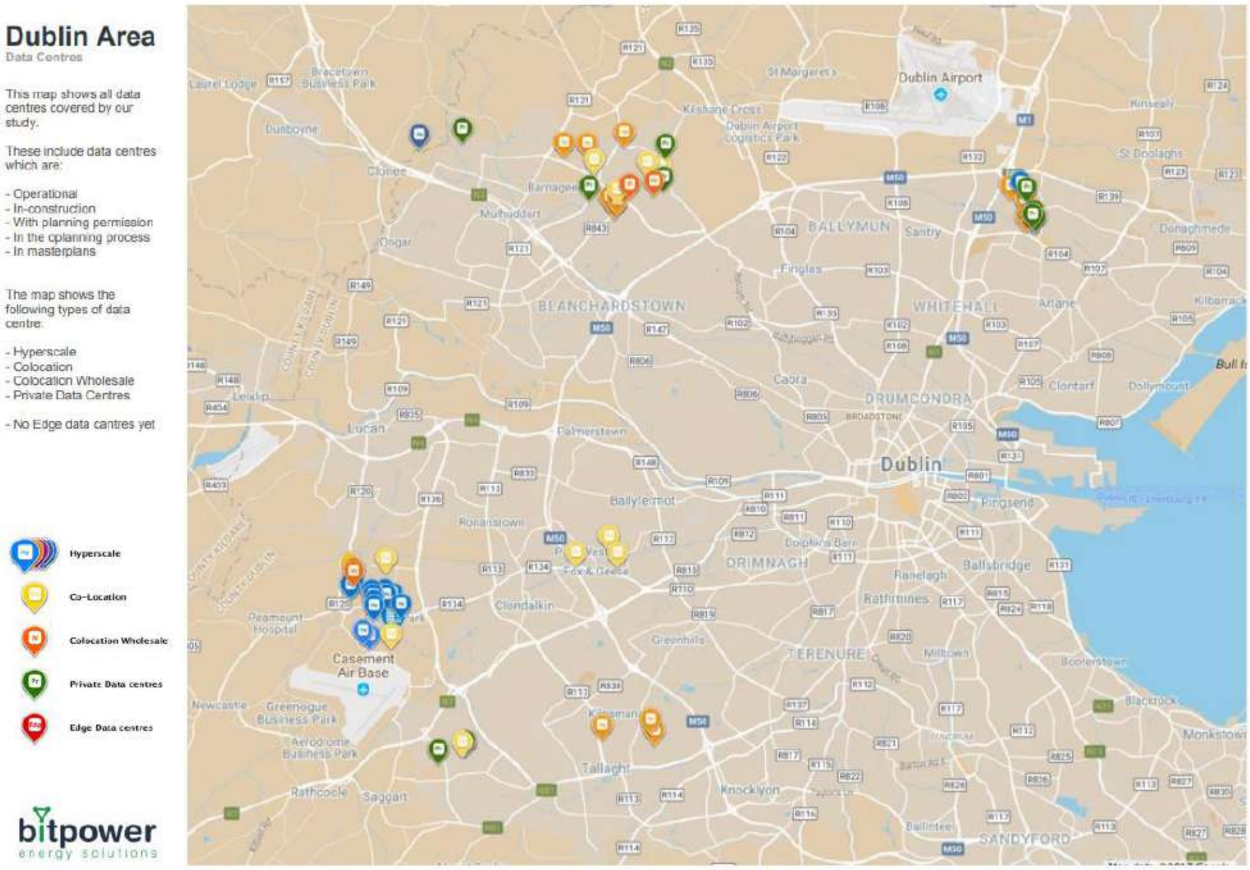


Figure 118: Data centre locations in Dublin map (source: Bitpower)

Future Electricity Demand

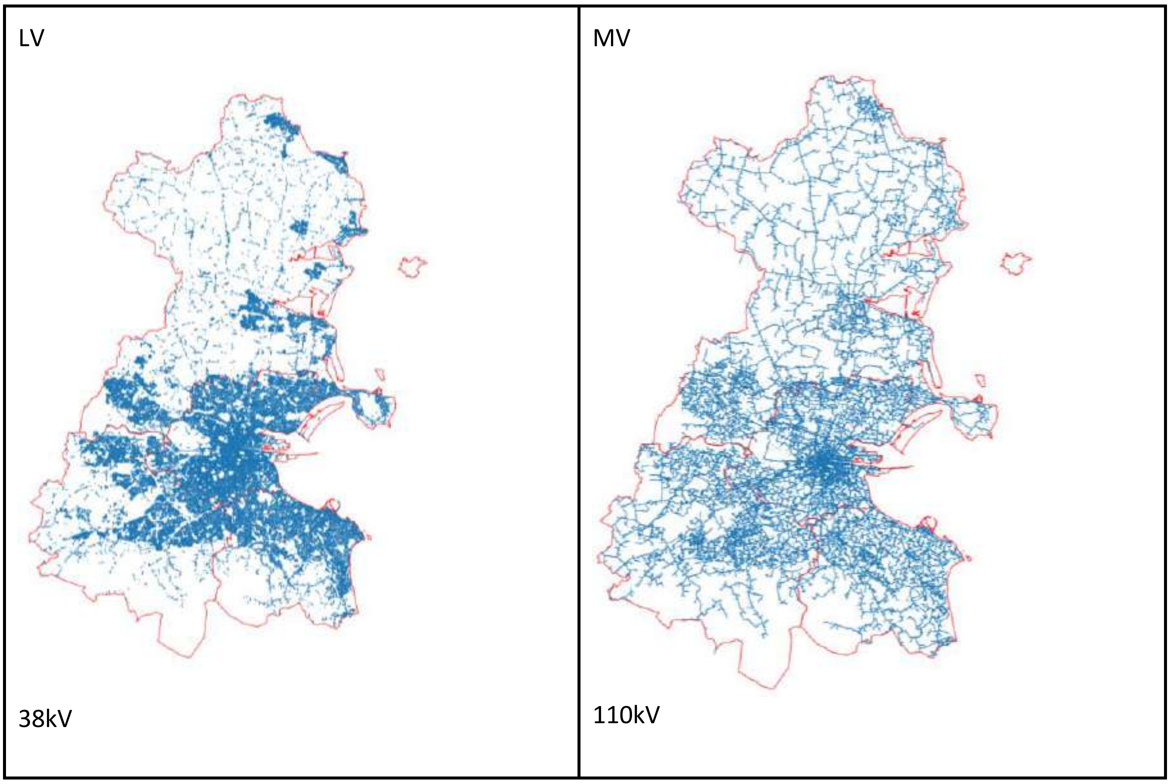
In order to project future electricity demands, Codema engaged with EirGrid's Energy Modelling team. Making use of EirGrid's support and report, All Island Generation Capacity Statement 2019 -2028[217], the growth factors used in this analysis were developed using forecasted economic growth from ESRI in conjunction with historical demand data. The demand forecasts also had to account for increases in both the housing stock and commercial properties in future years, whilst also considering the negating effects of increased energy efficiency in buildings.

Conveniently, these demand estimates have been provided under three key headings of residential, commercial and data centres, each of which had their own respective growth factors. Interestingly, the energy demand for 2021 was set to decrease from 2020, due to the economic downturn from the COVID-19 pandemic. However, this is set to revert and continue in an upward trend from 2022 onwards.

Electricity Grid Constraints

Spatial Mapping of Grid Data

The electricity grid transformer stations and distribution network was mapped in QGIS. The grid network included high, medium and low voltage infrastructure (abbreviated as HV, MV and LV respectively). The nominal voltage ranges in each voltage category can be seen in the figure below. It should be noted that urban MV networks are generally operated at 10kV as opposed to 20kV.



217 https://www.eirgridgroup.com/site-files/library/EirGrid/EirGrid-Group-All-Island-Generation-Capacity-Statement-2019-2028.pdf

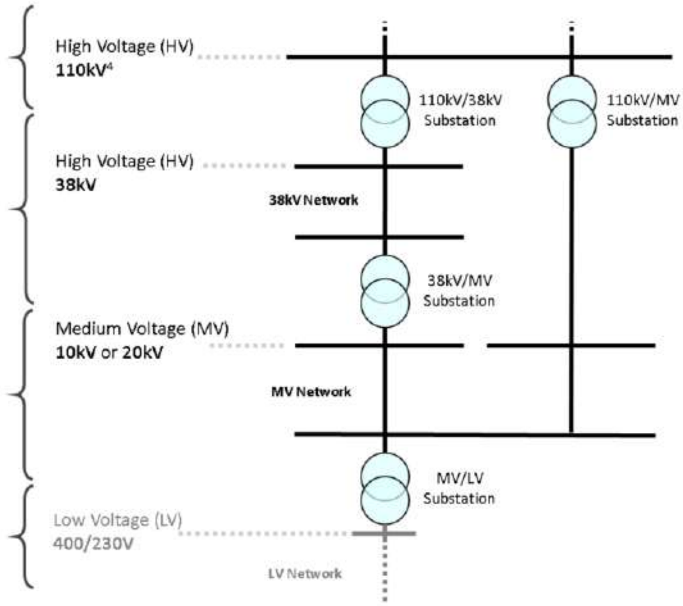


Figure 119: Distribution Network Nominal Voltages[218]

Each Small Area (SA) zone was linked to its corresponding substation in order to compare SA demand estimates to substation capacity. This was achieved by finding the nearest substation to each Small Area centroid along the closest MV lines[219][220].

Grid Constraint Mapping and Costing

Substation and line capacity are the key network constraints when it comes to electrification of heat and transport. From discussions with the ESB, the substation capacity is the primary indicator of grid constraints. By comparing the available capacity with the substation installed capacity, existing or upcoming grid constraints have been identified. Combining this information with average MV & LV grid upgrade costs from ESB Statement of Charges has allowed an electrical grid upgrade cost for each zone to be applied to each small area within the zone. These additional grid costs applied for residential heat pumps are shown in the map on the next page.

[218] https://www.esbnetworks.ie/docs/default-source/publications/doc-170220-fom-distribution-system-security-and-planning-standards.pdf?sfvrsn=d99501f0_0

[219] https://github.com/codema-dev/esb-network-pylib

[220] As ESB provides Substation capacity data by station name @ https://www.esbnetworks.ie/network-capacity-map and this is not listed in their closed-access CAD network files; their help was required to link these data sets

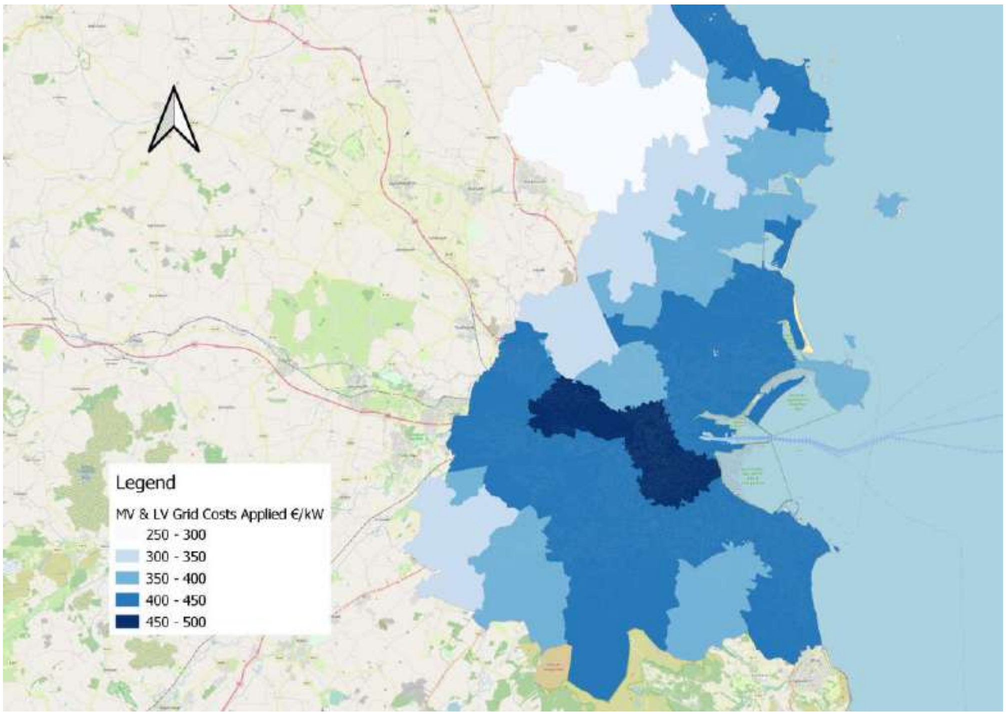


Figure 120: Map showing variations in electrical grid upgrade costs across Dublin

The Statement of Charges notes that existing homes whose current connections (typically 12kVA) will need to be upgraded (assumed to 16kVA) to service additional load from the installation of a heat pump (but also potentially EV charging and greater use of electric cookers). This connection upgrade charge is stated as being €1,539 for a single urban connection. This includes MV network costs but excludes trenching within the boundary of the site. Assuming a power factor of 0.95 for the heat pump load This translates to a LV & MV upgrade cost of €405/kWe.

For new connections the additional trenching cost is estimated at €6/m based on typical rates. A new single upgraded 16kVA connection will cost €3,506.

For commercial building heat pumps, the impact on the buildings MIC was assessed in order to determine if the HP installation resulted in the building breaking its existing MIC threshold and thus incurring additional cost for moving into a higher MIC band.

Special Load Readings

The ESB kindly provided a list of the 'Special Load Reading'[221] stations based in Dublin and electrical grid network data. These stations were subsequently geocoded using Nominatim. Nominatim is a search engine for OpenStreetMap data, which allows users to search for a name or address to find its geographic coordinate (approximate location). This enabled regions to be linked to their corresponding stations (and lines) and thus compare modelled regional loads to network capacity.

221 https://www.esbnetworks.ie/tns/publications/search-results?indexCatalogue=our%2Dpublications&searchQuery=special+load+readings&wordsMode=0

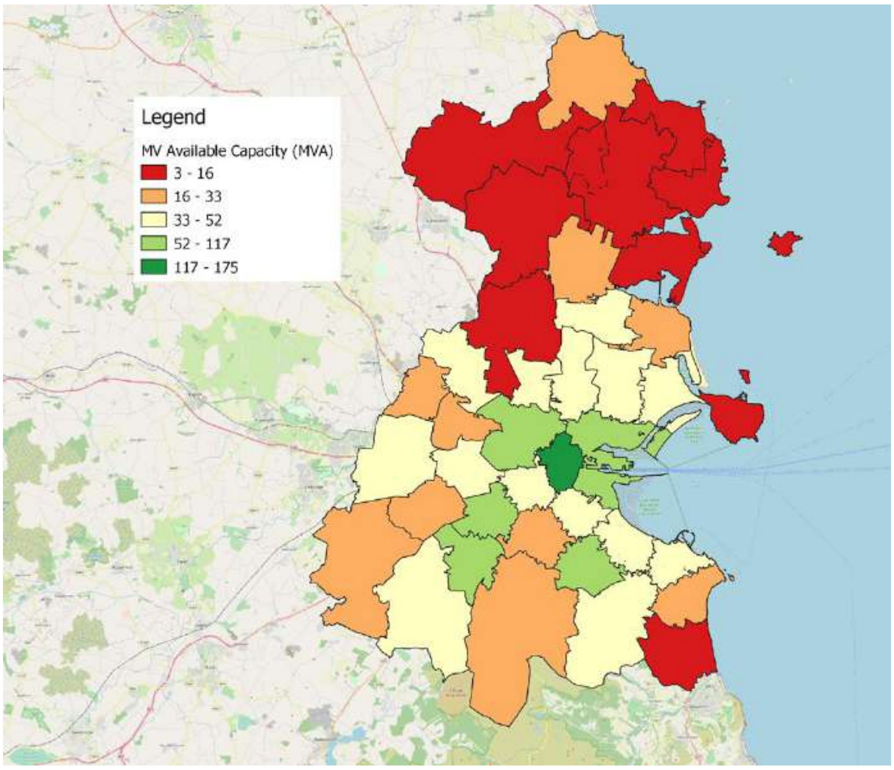


Figure 121: Available medium voltage electrical substation capacity (MVA) map

Another useful resource network capacity map[222] provides available capacity for all transformer stations. It also provides the parent name of the feeder station and feeder circuit from that station for all LV transformers. This is useful when dealing with individual buildings rather than considering regional constraints.

Dispatch Down on the Generation Side

As the proportion of intermittent renewables on the electricity grid grows, the percentage of power that can not be utilised due to constraints on the grid or to lack of demand during periods where electricity production is high is likely to increase. These periods are commonly referred to as dispatch down. In order to reduce the impact of these periods and in the case of constraints limit the cost of upgrading the grids, energy storage can be used to reduce the percentage of dispatch down.

There are many different forms of storage including electrochemical storage (battery storage), thermal energy storage, and mechanical energy storage. The cheapest of these is thermal energy storage, where the energy is stored as hot water rather than electricity.

In the future when large renewable electricity installations are likely to be prevalent in the region, there will also be an additional heat source in the form of curtailed electricity generation. Curtailed generation is electricity that is generated by renewable sources such as wind or solar but that cannot be used due to lack of demand or constraints on the electricity grid. This renewable electricity can be converted into heat via heat pumps or electric boilers to provide heating. In this respect, DH can also provide services to the grid in terms of frequency response and grid balancing. The utilisation of otherwise curtailed renewable electricity via DH also facilitates the use of cost-effective large-scale thermal energy storage, which is a fraction of the cost of battery storage and benefits from a much longer lifespan. This source has been included in the 2030 heat source breakdown. It should be noted that the assumed curtailment in this assessment of 8.6% (based on the average three-year curtailment from 2018 to 2020 from EirGrid) is likely to be a conservative estimate. If renewable generation outstrips demand in the way it should in the coming years, this potential curtailment figure is likely to increase, particularly if DH or other systems (batteries, flywheels, etc.) providing grid balancing are not also developed. For 2050 curtailment was assumed at 18% this is based on the assumed high capacity factor of offshore wind as the main renewable electricity generation in the Dublin region and the proximity of significant

[222] https://www.esbnetworks.ie/network-capacity-map

base load demand to these sources. Further research into the curtailment/dispatch down of large wind generators (particularly offshore wind).

Table 42: All-island dispatch down percentage of generation by year (source: Eirgrid)

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Total Dispatch Down Levels	2.2%	2.1%	3.2%	4.1%	5.1%	2.9%	4.0%	6.0%	7.7%	12.1%
Constraints	0.4%	0.8%	0.9%	1.4%	1.8%	1.4%	1.2%	2.2%	4.0%	6.2%
Curtailments	1.8%	1.3%	2.3%	2.6%	3.3%	1.5%	2.7%	3.8%	3.7%	5.9%

Table 2: All-Island Yearly Breakdown of Wind Dispatch-Down Levels into Constraints and Curtailments

Grid Electricity Emissions Factors

In order to assess the technology pathways which rely on the electrification of the heat and transport sectors, the following emission factors have been assumed up to 2050. The emission factors to 2030 have been determined based on analysis of the national grid performed by MaREI and emissions from 2030 to 2050 assume a linear reduction to zero in line with net zero targets for 2050.

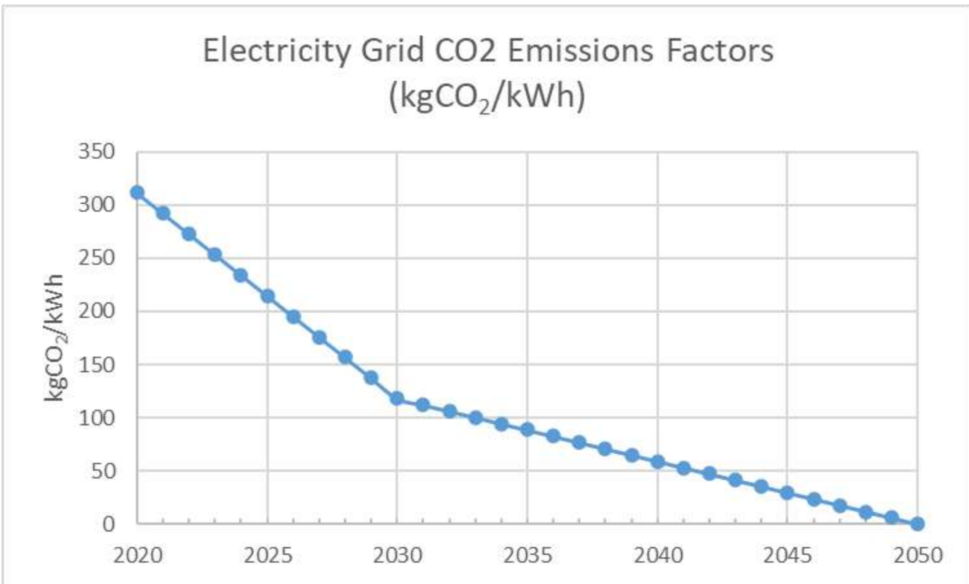


Figure 122: Electricity grid emissions factor trajectory to 2050

When it comes to assessing the emissions savings from renewable electricity generation such as solar and wind, the 2019 emissions factor of 0.3245 tCO_2/MWh was used. The most recent available grid emissions factor was for 2020 at the time of writing this report. However, the 2019 figure was considered more representative as 2020 was a particularly windy (high renewable generation) year with lower than usual demand due to the mild winter. This factor was also used, as over the life of this masterplan it is assumed that the current generation mix of fossil fuel and older renewable generation is what will be replaced by these new renewables.

Appendix E - Transport Sector Methodology

Current Transport Demand

Road Transport Emissions

Road transport demand and current supply has been modelled based on data provided by the National Transport Authority. The outputs from the Environmental Module of the East Regional Model (ERM) provided energy-related emissions data for all road transport links in the Dublin region. This regional model takes inputs from the National Demand Forecasting Model (NDFM) - a single, national system that provides estimates of the total quantity of daily travel demand produced by and attracted to each of the 18,488 Census Small Areas. Straight line links are created, overlapping the road and rail networks. The outputs from the trip generation process in the NDFM are assigned to these links between the various trip origins and destinations. The model is calibrated against numerous sources, including the 2016 CSO Census, 2017 National Household Travel Survey, 2019 National Travel Survey, and traffic count data collected by Transport Infrastructure Ireland and the various local authorities. The base year assumed in this model is 2016.

The main focus of the ERM model is on traffic volumes and flows. The add-on Environmental or "ENEVAL" module takes the outputs from the ERM and calculates the associated energy-related emissions along each link. The outputs relate to greenhouse gas emissions, local air pollutants and particulate matter. Particulate emissions related to tyre, brake or road wear are not considered.

The NTA's modelling of the road transport system in ENEVAL is quite complex, utilising a detailed breakdown of the road vehicle fleet makeup in the region, and emissions data from the COPERT database[223]. COPERT is the EU standard vehicle emissions calculator. It takes vehicle population, mileage, speed and other data such as ambient temperature as inputs and is generally used to calculate emissions and energy consumption for a specific country or region. Emissions are calculated for each individual link in the ERM using COPERT, and take into account the expected mix of vehicle types on each link, as well as modelled traffic conditions and speeds. For example, haulage routes such as the M1 motorway have a significant proportion of heavy goods vehicles assigned to them, while streets in the suburbs are assigned a far higher proportion of private car use.

The outputs from the NTA road transport modeling were provided to Codema as GIS shapefiles, presenting the emissions spatially on a link-by-link basis. This data could also be presented in the form of a grid representing areas of 100 metres x 100 metres. The grid output provides the option of presenting the emissions data in terms of specific regions, such as at a CSO small area level of granularity. When overlaid on a map of CSO small areas, many of the 100x100 grid elements can be seen to straddle two or more CSO small areas. An approximation was made in order to assign each grid element to a single CSO small area. The centroid of each 100m x 100m element was determined and the emissions values assigned to the corresponding small area within which the centroid sits. Presentation of the data in this way may be useful for comparing local air quality across the county.

Road Transport Energy Demand

Unfortunately, ENEVAL was not designed to provide any outputs in terms of energy demand. As Codema did not have access to all of the underlying data and calculations used in the ENEVAL process, the energy demand had to be reverse-engineered back to fuel consumption (petrol, diesel and electricity) based on the total vehicle-km per vehicle class (car, bus, HGV, etc.) and a breakdown of vehicle-km by fuel type, as provided by the NTA. As this level of detail was not available for each individual link, the energy demand analysis could not be performed on a link-by-link or 100 m grid basis. Instead, road transport energy demand was calculated at a county-wide level.

The total vehicle-km data provided to Codema and fuel split assumptions are provided in Table 43 The data included all journeys throughout the county of Dublin. This includes journeys whose origin and destination were both located outside of Dublin, with only the section completed within Dublin included in the data. The vehicle-km data provided relates to a typical midweek day. As no methodology for converting this to annual data was provided by the NTA, a

[223] COPERT emissions calculator, https://www.emisia.com/utilities/copert/

method was developed by Codema based on the results of the 2017 National Household Travel Survey (NHTS)[224]. The 2017 NHTS provided a breakdown of the average proportion of trips carried out by households on each day of the week, for both the Dublin City area and the Greater Dublin Area (GDA), which includes the four Dublin local authority areas, as well as Wicklow, Meath and Kildare. The NHTS data showed a significant variation in the volume of trips undertaken from one day of the week to the next, as shown in Table 43 below.

Table 43: Percentage breakdown of total weekly trips by day

Day of Week	GDA	Dublin City
Mon	11%	11%
Tue	16%	13%
Wed	20%	15%
Thu	17%	15%
Fri	18%	21%
Sat	9%	14%
Sun	9%	12%

As no other data was available for commercial transport activity, it was assumed that the proportionate split for household journeys could be applied across all vehicle classes. Sixty-nine per cent of the NHTS responses relating to the GDA came from within County Dublin. It was therefore decided to use the GDA data for any analysis, as it was likely to better capture the share of rural and highway trips, which might not be evident in the Dublin City data. Using the relative number of trips on an average weekend day compared to an average weekday, a formula was derived to determine the total annual vehicle-km per vehicle class:

Annual vehicle-km = [(typical weekday v-km * 5) + (proportion of trips on average weekend day/proportion of trips on average midweek day * typical weekday v-km * 2)] * 52

The 24-hour and calculated annual vehicle-km figures for each vehicle class are presented in Table 44.

Table 44: 24-hour and annual vehicle-km by vehicle class

Vehicle Class	24-hour vehicle-km	Annual vehicle-km
Car Employer's Business	3,269,688	1,036,730,341
Car Commute	6,018,813	1,908,404,122

[224] National Household Travel Survey 2017, https://www.nationaltransport.ie/planning-and-investment/transport-modelling/national-household-travel-survey/

Car Other	5,645,003	1,789,879,000
Car Education	158,814	50,355,659
Car Retired	674,456	213,851,902
Taxi	629,733	199,671,439
LGV	2,039,085	646,539,146
OGV1	403,809	128,037,000
OGV2 Permit Holder	51,684	16,387,610
OGV2 Non-Permit Holder	389,751	123,579,585
Bus	186,766	59,218,488

In order to work back from vehicle-km to energy demand, different approaches were used for the various vehicle classes, as described below.

Cars

Energy and emissions related to cars were calculated using the data available from the Irish Car Stock Model (version 2.4) produced by researchers in the Energy Policy & Modelling Group at University College Cork/MaREI[225]. This excel database provides a comprehensive breakdown of the Irish car stock by engine size and fuel type, based on 2018 National Car Test data. In order to apply this data to Dublin, the national average energy consumption in MJ/km was calculated, as well as the average emissions in gCO_2/km. The energy demand values assumed for electric vehicles in the UCC model were found to be on the low end of the scale, and were increased to the more typical value of 15 kWh/km, or 0.54 MJ/km. The six car categories in the previous table (including Taxi) were summed to give a total for annual vehicle-km, which was then multiplied by the calculated average energy and CO_2 emissions figures. These are presented below.

	Average CO_2 Emissions [gCO2/km]	**Average Energy Consumption [MJ/km]**	**Total Annual CO_2 Emissions [tCO_2]**	**Total Annual Energy Consumption [TJ]**
Car	169.35	2.26	880,447	11,749

Vans & Heavy Goods Vehicles

For vans and heavy goods vehicles, no existing energy and emissions model was readily available, so the COPERT 5.4 software package was instead used for these vehicle classes. The COPERT software required a number of inputs to calculate the emissions and energy demand. The main assumptions used and outputs from the model are presented in the table below. The mean activity level in km was taken from the CSO Transport Omnibus 2019 data for Goods Vehicles[226]. Vehicle stock numbers were then estimated by dividing the total annual vehicle-km for each vehicle class

[225] https://github.com/vor115384876/Irish-Car-Stock-Model
[226] https://www.cso.ie/en/statistics/transport/transportomnibus/

by the mean activity level. Lifetime cumulative activity in km was calculated based on an average vehicle age of 8.8 years[227]. All vehicles were assumed to be diesel. Given the average age of vehicles used, it was assumed that all engines were in the Euro 4 (vans) or Euro IV (trucks) bands. All vans were assumed to be in the N1-II vehicle weight category. Heavy goods vehicles were split into two categories, as per the NTA vehicle-km data. For the OGV1 vehicle class, it was assumed that all vehicles in this category were rigid 20-26 tonne trucks. For the OGV2 class, all vehicles were assumed to be articulated 40-50 tonne trucks.

Table 45: COPERT analysis for LGVs and HGVs

	Segment	Euro Engine Band	Stock [no. of vehicles]	Mean Activity [km]	Lifetime Cumulative Activity [km]	Annual Emissions [tCO_2]	Annual Emissions[tNOx]	Annual Energy [TJ]	Average Emissions [gCO_2/km]
LGV	N1-II	Euro 4	27,498	23,512	206,905	166,333	539	2,237	257
OGV1	Rigid 20 - 26 t	Euro IV	5,445	23,512	244,524	82,396	531	1,108	644
OGV2	Articulated 40 - 50 t	Euro IV	5,953	23,512	244,524	118,076	744	1,588	844

Buses

Energy demand and emissions relating to buses were calculated based on actual operational data provided by Dublin Bus for 2019.

	Average CO2 Emissions [gCO2/km]	Average Energy Consumption [MJ/km]	Total Annual CO2 Emissions [tCO2]	Total Annual Energy Consumption [TJ]
Bus	1,219	16.63	72,170	984

Calibration of outputs

It was inevitable that the figures calculated by Codema through the process described above would not match up perfectly with the emission totals provided by the NTA's more complex ENEVAL link-based analysis. This is due to a number of factors outlined below:

- The weekday to annual conversion factor may not have been consistent with what ENEVAL had used.
- In ENEVAL, speed is an important factor of the final emission values, with speed-based emission profiles employed for each vehicle type and emission category. This would certainly not have been captured as well in Codema's simplified approach for cars, which multiplies a standard emission rate by vehicle-km travelled. Similarly for goods vehicles, the COPERT analysis developed here used a standard set of assumptions as used by transport researchers at Trinity College Dublin[228] relating to the mode share on urban, rural and highway type roads, and the average speed on each of these road types.
- The standard emissions rates for each vehicle class might not be consistent across the Codema and NTA approaches.

[227] https://www.acea.auto/files/report-vehicles-in-use-europe-january-2021-1.pdf
[228] http://www.tara.tcd.ie/handle/2262/86695

- The ENEVAL link-based output emissions incorporate the emissions from the traffic queuing at the end of the link, and will use estimates of average link-speeds which incorporate these junction delays. This was not captured in Codema's vehicle-km based approach.

In order to quantify this gap and allow for a calibration of Codema's energy and emissions modelling, the total combined emissions from the two approaches was compared. It was found that Codema's modelling only accounted for 81% of the total emissions produced by the ENEVAL model. A correction factor was thus applied to the emissions and energy demand for each vehicle class to ensure that the totals were consistent with the ENEVAL links-based outputs. The adjusted CO_2 emissions and energy demand figures for each vehicle class are presented in Table 46 below:

Table 46: Adjusted baseline CO_2 emissions and energy demand

	Annual emissions (tCO_2)	**Annual energy (TJ)**
Car	1,085,222	14,483
LGV	205,019	2,757
HGV	247,097	3,323
Bus	88,955	1,213
Total	1,626,294	21,777

Rail Transport Energy Demand & Emissions

The road transport GIS shapefile provided by the NTA included links along each of the existing rail lines in Dublin, including the Luas and DART; however, no energy or emissions data was assigned to them. A separate model therefore had to be developed to calculate rail energy demand and emissions. A simple model was created, based on the length of both light rail and heavy rail track within the county and the total annual number of services along each section of line. For Luas services, tables showing average frequency in minutes are provided on the Luas website for each station.[229] These tables were used to first calculate the typical number of daily services along each section of track, before converting this to an annual number of services. The total annual number of services along each section of heavy rail track was calculated using Irish Rail printed timetables.[230] This included all Public Service Obligation (PSO) services operated by Irish Rail within the bounds of County Dublin, including DART, Commuter and Intercity. The average fuel consumption per vehicle-kilometre travelled was determined for Luas and DART services, based on actual 2019 operational data published by SEAI[231] and Irish Rail[232]. A specific breakdown of diesel train energy consumption was not available for the Dublin area, so the national average was applied for commuter and intercity services to and from Dublin. The total annual energy demand relating to each rail service was determined using the following formula:

Energy demand = length of track x no. of services per year x average energy demand per vehicle-km

CO_2 emissions from rail were calculated by applying SEAI's standard carbon intensity conversion factors, as described earlier, to the energy demands determined above. The values for electricity are based on the national average carbon

[229] https://luas.ie/map/
[230] https://www.irishrail.ie/en-ie/train-timetables/timetables-by-route
[231] https://www.seai.ie/publications/Energy-in-Ireland-2020.pdf
[232] https://www.irishrail.ie/Admin/IrishRail/media/Content/About%20Us/CIE-Iarnrod-Eireann-Annual-Report-2019.pdf

intensity of electricity generated over a given year, and are updated annually. For this calculation, the 2019 national average electricity carbon intensity factor of 331.4 gCO_2/kWh was used[233]. Table 47 below provides a summary of the energy demand and CO_2 emissions per vehicle-km as used in the model.

Table 47: Average light and heavy rail energy demand and CO_2 emissions per vehicle-km

	Diesel train	DART	Luas
Energy consumption TFC/vehicle-km (kWh/v-km)	30.5	11.7	5.63
CO_2 emissions/vehicle-km (gCO_2/v-km)	8,057	3,874	1,864

In order to allow for the determination of local air emissions, the length of rail line link in each small area was calculated and the emissions and energy demand assigned proportionately to each.

The total final energy demand and emissions relating to each rail mode within the County of Dublin is presented below in Table 48.

Table 48: Total final energy and emissions from rail

	DART	Luas	Commuter/Intercity	Total
Annual final energy consumption (TJ)	87.8	87.00	292.2	467.0
Annual CO_2 emissions (tCO_2)	7,195	7,131	21,420	35,747

Business-As-Usual Projected Transport Demand

Road Transport Energy Demand & Emissions

For future projected road transport emissions, the NTA provided Codema with the outputs from their 2028 ENEVAL model. This consisted of the same data as that described above for the current situation, including link-based emissions, vehicle-km by vehicle class and trip demand by mode. The 2028 model run took into account a number of major transport projects planned for the East Region, many of which were set out in the 2016-2035 GDA Transport Strategy. The full list of projects included in the model run are listed below:

- Interim DART Expansion Programme (non-tunnel elements) including additional stations at Kishogue, Cabra, Pelletstown, Woodbrook, Kylemore and Glasnevin
- Metrolink (to Charlemont)
- Luas Cross City incorporating Luas Green Line Capacity Enhancement - Phase 1
- Radial Core Bus Corridors
- BusConnects Fares / Ticketing
- BusConnects Routes and Services
- Rail and Bus based P&R provision (partial implementation by 2028)
- Greater Dublin Area Cycle Network Plan (excluding Radial Core Bus Corridor elements)

[233] https://www.seai.ie/data-and-insights/seai-statistics/conversion-factors/

- Widening of the M7 between Junction 9 (Naas North) and Junction 11 (M7/M9) to provide an additional lane in each direction
- Capacity enhancement and reconfiguration of the M11/N11 from Junction 4 (M50) to Junction 14 (Ashford) inclusive of ancillary and associated road schemes, to provide additional lanes and upgraded junctions, plus service roads and linkages to cater for local traffic movements
- N3 Castaheany Interchange Upgrade/N3 M50 to Clonee
- N3–N4: Barnhill to Leixlip Interchange
- North-South Road – west of Adamstown SDZ linking N7 to N4 and on to Fingal
- Glenamuck District Distributor Road
- Leopardstown Link Road Phase 2
- Porterstown Distributor Link Road
- R126 Donabate Relief Road: R132 to Portrane Demesne
- Oldtown-Mooretown Western Distributor Link Road
- Swords Relief Road at Lord Mayors
- Poolbeg development roads
- Cherrywood development roads
- Clonburris development roads
- Dublin City Centre Parking Constraint
- Revised Irish Rail timetable
- R132 Reconfiguration in Swords
- N52 Tullamore Kilbeggan Link
- N2 Rath roundabout to Kilmoon Cross
- N3 Virginia bypass
- M4 Maynooth to Leixlip
- M50 Dublin port south access road
- N2 Slane Bypass
- N52 Ardee Bypass
- M11 Gorey to Enniscorthy
- Sallins Bypass (R407)
- N2 Ardee to Castleblaney
- N2 Clontibret to N.I. Border

No NTA model outputs were made available to Codema beyond 2028. In order to generate road transport emissions and energy demand projections out to 2030 and 2050, the 2028 data was extrapolated forward. For the 2030 scenario, a simple linear projection was employed, based on the average annual change in vehicle-km for each vehicle class between 2016 and 2030. For projecting out to 2050, an alternative approach was used, based on expected population growth in the Dublin region. It was assumed that the transport demand per capita would remain constant from 2030 to 2050. Expected population figures for Dublin to 2040 were available from the "Regional Demographics and Structural Housing Demand at a County Level" report produced by the ESRI in December 2020[234]. The average projected growth rate between 2031 to 2040 was then used to extrapolate the growth in Dublin's population out to 2050. This corresponds to an average annual increase of roughly 0.35% per annum over this period. The vehicle-km totals for 2050 were then calculated using the formula below:

2050 v-km = 2030 v-km x 2050 population / 2030 population

The same methodology as before was used to convert from 24-hr vehicle-km to annual vehicle-km for each vehicle class. For calculating emissions and energy demand for cars to 2030 and 2050, data from UCC's Irish Car Stock Model was again employed, using modified outputs from their "Business as Usual" projection. The modification relates to the emissions from EVs, which were altered to include the emissions from power generation, using projected SEAI emissions factors for 2030 and 2050. This methodology assumed a low rate of growth in the numbers of electric vehicles on the roads, based on the market share of newly registered vehicles in 2018. This also assumed that the rate of biofuel

[234] https://www.esri.ie/publications/regional-demographics-and-structural-housing-demand-at-a-county-level

mixing remained at 6% and 7% of energy content for petrol and diesel, respectively. For vans, trucks and buses, it was assumed that all would remain fuelled by diesel (with 7% biofuel mix) in the Business-as-Usual scenario. No energy efficiency increases were factored in for any of the vehicle classes. For the 2030 emissions, it was found that Codema's modelling only accounted for 78% of the total emissions produced by the ENEVAL model. A correction factor was again applied to ensure that the totals were consistent with the ENEVAL links-based outputs. The same factor was applied also to the 2050 figures. The adjusted CO_2 emissions and energy demand figures for each vehicle class are presented in Table 49:

Table 49: Business as usual CO_2 emissions and energy demand

	2030 annual emissions (tCO_2)	2030 annual energy (TJ)	2050 annual emissions (tCO_2)	2050 annual energy (TJ)
Car	917,956	13,117	986,115	14,090
LGV	294,474	3,961	316,339	4,255
HGV	374,547	5,038	402,357	5,412
Bus	115,201	1,572	123,755	1,688
Total	1,702,178	23,686	1,828,566	25,445

Rail Transport Energy Demand & Emissions

Rail vehicle kilometres were again used to generate projections of rail energy demand and emissions out to 2030 and 2050. In order to determine the total distance travelled by each mode of rail transport, the proposed light and heavy rail networks in 2030 and 2050 were mapped out spatially using QGIS. This was based on the projects described in the NTA's 2016-2035 GDA Transport Strategy. In many cases, the final route selection has yet to be made, so the emerging preferred routes have been used where available. A summary of the rail projects included for the 2030 and 2050 Business-as-Usual scenarios is detailed below.

Table 50: BaU light and heavy rail projects scheduled by 2030 and 2050

Project Name	Base Year	2030	2050
Metrolink		X	X
Luas Finglas		X	X
Luas Bray			X
Luas Poolbeg			X
Luas Lucan			X
DART+ (non-tunnel)		X	X
DART+ Tunnel			X

Full Electrification			

Many of these projects are still in very early planning stages, so limited data was available in terms of projected frequency of service and the degree of electrification over the given timelines. Some assumptions therefore had to be made in order to estimate the total number of annual services along each line, and associated energy demand and carbon emissions. These are outlined in the table below.

Table 51: Assumptions made in calculations of annual number of services

Project Name	Assumptions
Metrolink	Assuming 2 minute frequency (as per 2020 Public Consultation report[235]) for 6 hours per day, 10 minute service for all other times.
Luas Finglas	Based on 8 services per hour as stated in the 2020 Public Consultation document[236]. Assumed only 6 services per hour on Saturday and Sunday. 18 hours of service per weekday as per Tallaght Red line, 17 hours on Sat/Sun.
Luas Bray	Assumed the same frequency as the existing service from Sandyford to Bride's Glen.
Luas Poolbeg	Assumed the same frequency as the existing Point-Busáras section of Luas Red line.
Luas Lucan	Assumed the same capacity as proposed Luas Finglas.
Luas Green	Assumed increase in frequency along Dominick St-Broombridge and Broombridge-Parnell St sections to match projected frequency along Finglas extension. Luas line to be replaced by MetroLink along the section from Charlemont to Sandyford.
DART+ (non-tunnel)	Peak commuter services (Hazelhatch-Connolly) due to increase from 2 to 7 with DART+ South West[237]. Assumed 50% diesel for 2030. Total number of services increased proportionally. Train capacity due to increase from 6 trains per hour to 12 trains per hour on DART+ West project. Assumed this will equate to a doubling in the total number of services across each section of the route. Assumed 50% increase in number of services from Drogheda to Bray by 2050.
DART+ Tunnel	Assumed same frequency as existing Connolly to Bray DART service - i.e. 10 minute frequency at peak hours

Using the assumptions above, the total annual energy demand and carbon emissions for each rail mode was calculated for both 2030 and 2050. An estimate was also made for rail freight, which is extremely small in Ireland. The CSO Transport Omnibus 2020 provides a breakdown of national freight volumes in tonne-kilometres by goods type. The Rail Freight Strategy 2040, published in 2021, states that only two rail freight routes are currently active in Dublin, operating from Dublin Port to Tara Mines and Ballina[238]. It was assumed in this analysis that the carbon emissions per tonne-km

[235] https://www.metrolink.ie/#/consultation
[236] https://www.luasfinglas.ie/#/home
[237] https://www.dartplus.ie/en-ie/home
[238] https://www.irishrail.ie/Admin/getmedia/685e9919-f012-4018-879b-06618bb536af/IE_Rail-Freight-2040-Strategy_Public_Final_20210715.pdf

from rail freight are just 16% of that of road freight, as reported in the Rail Freight Strategy 2040. The results from this analysis are presented below:

Table 52: BaU summary of rail energy demand and emissions for 2030 and 2050

	DART	Luas	Commuter /Intercity	Freight	Total
Annual final energy consumption 2030 (TJ)	214.7	139.8	145.6	3.3	503.4
Annual CO_2 emissions 2030 (tCO2)	6,398	4,168	10,675	239	21,480
Annual final energy consumption 2050 (TJ)	307.5	175.8	60.3	3.3	544.8
Annual CO_2 emissions 2050 (tCO_2)	0	0	0	0	0

Low-Carbon Potential

Two low-carbon scenarios were examined to compare against the "Business-as-Usual" scenario. Scenario A: CAP 2019 was based on the relevant policies and targets as set out in the Climate Action Plan 2019 and listed in the following section. Scenario B: Increased Ambition aimed to go beyond the targets set out in CAP 2019, with the goal of achieving a 51% reduction in transport emissions by 2030, and a complete decarbonisation of the transport system by 2050.

Scenario A: CAP 2019

In this scenario, energy demand and emissions from the transport sector have been modelled based on the actions outlined in the Irish Government's 2019 Climate Action Plan. The majority of the actions listed for the Transport sector are planned for the period up to 2030. It was assumed that vehicle-km values for each vehicle class would be consistent with the Business-as-Usual scenario. A summary of the relevant policies and targets from CAP 2019 taken into account in Scenario A are listed below:

Table 53: Transport policies and targets outlined in Climate Action Plan 2019

Climate Action Plan 2019 Transport Policies & Targets
936,000 EVs by 2030 - 840,000 passenger EVs - 95,000 electric vans and trucks - 1,200 electric buses Will require 180,000 EVs on the road by 2025
45-50% reduction in transport emissions by 2030, substantial acceleration in second half of decade
Ban sale of new non-zero emissions small vehicles by 2030
40% of new vehicles sold to be EVs over the 12 intervening years up to 2030. Use the combination of VRT, motor tax, fuel tax and carbon pricing to support earlier payback and the more ambitious adoption of EVs.

Raise the blend proportion of biofuels in road transport to 10% in petrol and 12% in diesel
No urban bus fleet diesel-only purchases from 1 July 2019
All public PSO urban bus fleets to be Low Emission Vehicles (LEVs) by 2035
50% increase in bus passenger numbers over lifetime of Bus Connects project
No NCT Certificate to be issued for non-zero emissions cars post-2045
Deliver 14 public CNG fuelling stations as part of the Causeway Project, with a view to further expansion of the network

Where targets have been presented at a national level, these have been scaled down proportionately to the Dublin county level. For the EV targets, the passenger EV target for 2030 has been scaled down based on the number of private cars registered in Dublin in 2019 compared to the country as a whole. This data is available from the CSO Transport Omnibus statistics, which are updated annually[239]. The values for electric vans and trucks for 2030 were also determined based on this CSO data. It was assumed that 90% of the van and truck target would be met by vans, with the remaining 10% met by trucks.

Road Transport Energy Demand & Emissions

In order to calculate the energy and emissions reductions from electrified cars, vans and trucks, the total kilometres travelled by EVs in each of these vehicle classes was first calculated. Average annual vehicle-km figures for Dublin, also taken from the CSO Transport Omnibus 2019, were multiplied by the total projected number of electric vehicles in each vehicle class for 2030. For cars, the emissions and energy demand values per kilometre used for electric vehicles were based on outputs from UCC's Irish Car Stock Model. For vans and trucks, the previous Business-as-Usual COPERT outputs were modified. It was conservatively assumed that the electrification of these vehicles would result in a decrease of 50% in final energy demand per km. Emissions from electric vehicles were calculated based on projected electricity grid carbon intensity figures. It was assumed that cars and vans would all be electrified by 2050, with the majority of HGVs still fuelled by diesel.

For buses, a more ambitious target set out in the BusConnects programme subsequent to the publication of the CAP 2019 has been considered in Scenario A. This increased target is to convert the entire Dublin Metropolitan Area's bus fleet (of 1,139 vehicles in 2020) to LEVs by 2032, and solely to zero emissions vehicles (ZEVs) by 2035[240]. The definition of a Low Emission Vehicle, as provided in the Government's Low Emission Vehicle Taskforce, is quite broad, and includes mild hybrids, plug-in hybrids, CNG, LNG and LPG fuelled vehicles, in addition to battery electric and hydrogen fuel cell electric vehicles[241]. This stems from the EU's Alternative Fuels Infrastructure Directive, which sets out that Member States must set out a strategy to support the development of sustainable alternative fuels for the transport sector. Recent studies, including the "Report on Diesel- and Alternative-Fuel Bus Trials" prepared for the Department of Transport in December 2019[242], have shown that there is little or no improvement in energy or emissions in switching from diesel to gaseous fuels, and that switching to hybrid diesel buses would result in lower emissions and lower energy demand than switching to CNG fuelled buses. Electric buses came out as the most efficient in final energy terms, and with the benefit of no local NOx or energy-related particulate emissions. Codema's analysis therefore assumed that post-2019, no new bus purchases would be gas powered, and instead would be either fully electric (either battery or hydrogen fuel cell) or diesel hybrid vehicles. Based on the current rate of fleet replacement, it could take 14 years to replace the entire Dublin Bus fleet. An increased rate of fleet renewal will therefore be required in order to reach the 2032 and 2035 targets, and it is likely that this will be focused towards the end of this period. The below table shows the fleet fuel mix assumed in Scenario A in order to meet these targets. By 2030, any diesel-only buses remaining in the fleet will be Euro VI vehicle emissions standard compliant. For the purposes of this analysis, it is assumed that each vehicle travels the same annual distance.

[239] https://www.cso.ie/en/statistics/transport/transportomnibus/
[240] https://busconnects.ie/initiatives/low-and-zero-emission-bus-fleet/
[241] https://www.gov.ie/en/publication/101f0-low-emission-vehicle-taskforce-phase-2-report/
[242] https://www.gov.ie/en/publication/7251e2-low-emission-bus-trials-report/

Table 54: CAP 2019 assumed fleet fuel split for buses

	2019	2030	2032	2035
Diesel	100%	15%	0%	0%
Diesel hybrid	0%	35%	30%	0%
Elec (BEV or FCEV)	0%	50%	70%	100%

For buses, the following energy demand and emissions factors per vehicle-km were assumed, based on actual Dublin Bus data from 2019, findings from the "Report on Diesel- and Alternative-Fuel Bus Trial" and hydrogen fuel cell efficiency figures published by Transport & Environment[243].

Table 55: Bus energy demand and emissions by fuel type

		FCEV	BEV	Diesel (12% vol. biofuel blend)	Diesel Hybrid
Energy demand per km (MJ/km)		11.2	6.8	16.6	14.1
Emissions per km (gCO_2/km)	2030	368	223	1084	921
	2050	0	0	1084	921

Rail Transport Energy Demand & Emissions

The passenger rail projects outlined in the CAP 2019 were all previously included under the GDA Transport Strategy 2016-2035. As such, the only change to the energy demand and emissions values used in the Business-as-Usual Scenario was the full electrification of rail services by 2050.

Scenario B: Increased Ambition

This scenario started out with the measures outlined in Scenario A and increased the level of ambition for each mode in line with what was deemed practically feasible.

Cars:
For 2030, the same number of EVs was assumed as per Scenario A (213,000). A 23% reduction in vehicle-km travelled by non-EV cars was included in order to reach the 51% overall target. For 2050, all cars were assumed to be electric, with a 50% overall reduction in vehicle-km compared to the Business-as-Usual Scenario. It was assumed that half of this reduction in distance travelled could be accounted for by e-bikes, with the remainder evaporating or shifting to public transport or zero carbon walking or cycling.

LGVs:
For 2030, a 5% overall reduction in vehicle-km was modelled compared to the BaU Scenario from improved logistical planning. It was assumed that 40% of the remaining vehicle-km would be travelled via electric vehicles, with a further 10% of vehicle-km shifted to e-cargo bikes. For 2050, the same 5% reduction in vehicle-km resulting from improved

[243] https://www.transportenvironment.org/discover/electrofuels-yes-we-can-if-were-efficient/

efficiencies was assumed, with 25% of vehicle-km shifted to e-cargo bikes. The remaining vehicle-km were all travelled by electric van.

HGVs:
For 2030, a 5% overall reduction in vehicle-km was modelled compared to the BaU Scenario from improved logistical planning. 5% of remaining vehicle-km were shifted to diesel rail, with another 20% of vehicle-km travelled by battery electric vehicles. For 2050, again a 5% reduction in vehicle-km resulting from improved efficiencies was assumed. A further 10% of vehicle-km was carried out by electric rail, and the remainder completed via electric vehicles.

Bus:
In the Increased Ambition Scenario, a 25% increase in bus service (vehicle-km) was modelled. It was also set out that all new urban bus purchases would be fully electric from 2022 onwards. This would lead to an accelerated transition away from diesel hybrid vehicles and instead towards fully electric vehicles. The modelled fleet breakdown is provided below.

Table 56: Increased Ambition assumed fleet fuel split for buses

	2019	2030	2032	2035
Diesel	100%	15%	0%	0%
Diesel hybrid	0%	15%	15%	0%
Elec (BEV or FCEV)	0%	70%	85%	100%

Rail:
For passenger rail, Scenario B assumed that the entire rail network would be fully electrified by 2030. It was assumed that this would be achieved through a combination of direct electrification using overhead lines and hybrid battery electric carriages, which can be powered either via overhead lines or onboard batteries. Energy savings were calculated based on the assumption of 35% tank to wheel efficiency of diesel trains, versus 95% efficiency for directly electrified trains. Future energy demand and emissions for heavy rail were calculated using the average energy performance of existing DART rolling stock. The resulting energy demand and CO_2 emissions are presented below:

Table 57: Increased Ambition rail energy demand and emissions

	DART	Luas	Commuter /Intercity	Total
Annual final energy consumption 2030 (TJ)	214.7	139.8	55.8	410.2
Annual CO_2 emissions 2030 (tCO_2)	6398	4168	1662	12228
Annual final energy consumption 2050 (TJ)	307.5	175.8	60.3	543.6
Annual CO_2 emissions 2050 (tCO_2)	0	0	0	0

Costs & Constraints

Table 58: Transport infrastructure costs and sources

	million€/km	Source
DART+ Tunnel	789	https://www.irishtimes.com/news/environment/cost-of-developing-dart-underground-metro-line-to-exceed-10bn-1.4725014
New Luas lines	250	https://www.tii.ie/public-transport/projects-and-improvements/p-t-active-projects-list/pt-active-list-07april21.pdf
Metrolink	158	https://www.nationaltransport.ie/details-of-metrolink-emerging-preferred-route-announced/
Typical new road	60	https://www.sustrans.org.uk/our-blog/news/2019/november/common-myths-about-investment-in-walking-and-cycling-busted-by-research-report
BusConnects	10	https://www.nationaltransport.ie/nta-publishes-details-of-costs-relating-to-busconnects-dublin/
DART+ electrification	3.5	https://www.nsar.co.uk/wp-content/uploads/2019/03/RIAECC.pdf
Road electrification	3.1	https://www.transportenvironment.org/wp-content/uploads/2021/07/2021_04_TE_how_to_decarbonise_long_haul_trucking_in_Germany_final.pdf
High quality cycle track	1.6	https://www.sustrans.org.uk/our-blog/news/2019/november/common-myths-about-investment-in-walking-and-cycling-busted-by-research-report
Greenfield cycle track	0.05	https://ecf.com/news-and-events/news/how-much-does-cycle-track-cost
Signalised pedestrian crossing	0.01	https://irishcycle.com/2021/12/30/a-lot-of-walking-and-cycling-money-will-bring-a-lot-of-waste/
		(where prices in GBP, conversion rate of 1.2 used)

Appendix F - Socio-Economic Impacts

Based on the proposed low-carbon pathways outlined in this document, Codema carried out an assessment of the potential carbon, economic and social impact of this. The results of this assessment highlight the carbon saving, renewable energy generation and the economic and social impact of the recommendations. This impact assessment includes a quantitative and qualitative analysis of the socio-economic impacts using key performance indicators in areas such as job creation as well as the economic, environmental and health benefits.

It should be noted that the low-carbon pathways highlighted in this report showcase the opportunities to increase renewable energy and reduce emissions within the Dublin Region. By making use of low-carbon technologies and increasing renewable energy, this can provide multiple opportunities – by using indigenous, sustainable sources to meet Dublin's energy needs, the region can reduce its reliance on fossil fuel imports, and by making use of local solutions to reduce emissions, it can help generate more employment for Dublin's citizens. Employment generation in the low-carbon, clean energy industry would mean that a number of citizens would need to be upskilled for the new roles. By ensuring that citizens are upskilled in the area of energy generation and low-carbon technologies as Dublin transitions to a clean and healthy region, this can ensure a more just transition for the Dublin Region's citizens.

Improving Dublin's built environment and helping to facilitate energy efficiency improvements in the housing stock can directly reduce energy demand and emissions, as well as impact home-owners' and tenants' utility bills, and can help reduce fuel poverty. By improving the heating sector and ensuring adequate low-carbon heating infrastructure is in place to meet Dublin's long term decarbonisation goal, the heating sector can help reduce emissions, create jobs and can provide citizens with warmer homes. By expanding charging infrastructure in strategic locations and investing in cleaner modes of public transportation, the region can reduce pollutants from the transport sector. Furthermore, improving road networks can help encourage more cycling and walking, which helps keep citizens active and can be a step forward towards the decarbonisation of the transport sector.

'A healthy population is a major asset for society, and improving the health and wellbeing of the nation is a priority for the Government and the whole of society. This means that all sectors of society and the whole of Government need to be proactively involved in improving the health and wellbeing of the population'[244].

As the above quotation from Ireland's framework for health and well-being indicates, health policy has increasingly shifted from a narrow focus on health service provision and treating those in ill health to a ''whole systems'' approach to health and well-being. This approach recognises the importance of social and environmental determinants of health and well-being, which, in turn, necessitates a whole-of-government and whole-of-society response to embed health and well-being within a range of policy sectors.

Air Quality & Air Pollution

Air quality is a measurement of the concentration of specific pollutants harmful to human health. Air quality policy focuses on the reduction of pollutants, both GHGs and the more immediate, harmful particulates and dioxins. Reducing the concentration of GHGs means lessening or eliminating the use of carbon-based fuels and moving to renewable sources of energy and carbon sequestration by green infrastructure.

The Environmental Protection Agency (EPA) has stated that **'***Ireland's air quality currently is good, relative to other European Union (EU) Member States, but maintaining this standard is a growing challenge.'*[245] Ireland's monitored air quality is within EU limits, however despite this, the levels of particulate matter have become a growing concern. During the colder winter months, air quality and health is impacted by increased fossil fuel burning and in Dublin we face potential exceedance of nitrogen dioxide limit due to heavy reliance on private motor vehicles.

[244] Healthy Ireland Framework 2019-2025
[245] https://www.epa.ie/irelandsenvironment/air/

The World Health Organisation (WHO) estimates that more than 400,000[246] premature deaths are attributable to poor air quality in Europe annually. The WHO has described air pollution as the 'single biggest environmental health risk'.

Air pollution has put an increased risk to our environment and health, with the most vulnerable more likely to be at risk. In Ireland, the number of premature deaths attributable to air pollution is estimated at 1,300 people and is mainly due to cardiovascular disease[247] The economic impact is also significant, with the increased costs of healthcare and lost working days.

Table 59: GHGs and Pollutants in the Dublin Region

Abbreviation	Description
NO_x	Nitrogen Oxides: at low concentrations can lead to eyes, nose and respiratory irritation along with fatigue and nausea.
NO_2	Nitrogen Dioxide: same effects as other Nitrogen Oxides but produced in higher amounts.
PM_{10}	Particulate Matter: can lead to respiratory complications including asthma and lung cancer.
$PM_{2.5}$	Fine Particulate Matter: can lead to respiratory complications including asthma and lung cancer, as well as cardiopulmonary complications.
HC	Hydro-Carbons: non-combusted fuel that is toxic in high concentrations.
CO	Carbon Monoxide: odourless gas that causes respiratory problems at lower concentrations and asphyxiation at higher concentrations.
CO_2	Carbon Dioxide: a greenhouse gas with negligible health impacts but strong impact of global greenhouse effect.
C_6H_6	Benzene: can be damaging to aquatic life and water supply in sufficient concentrations.
CH_4	Methane: a greenhouse gas that traps significantly more heat than CO2 but decays at a faster rate.
C_4H_6	1, 3 Butadiene: at low concentrations can irritate eyes, nose and throat and lead to heart and lung damage through prolonged exposure. High exposure can lead to central nervous system damage. Breaks down quickly in sunlight.

Air pollutants depend greatly on the climate and characteristics of the area, and the two sectors that impact most on air quality are home heating and transport. The most significant air emissions are particulate matter (PM_{10} and $PM_{2.5}$), which mainly arise from domestic solid fuel burning and nitrogen dioxide (NO_2) from transport emissions. The max allowable annual average concentration of NOx in the atmosphere is 32µg/m^3 for all EU member states[248]. A maximum one-hour exposure of 140µg/m^3 should not be exceeded more than 18 times a year. Similarly, for PM, the maximum one-hour exposure level is permitted to exceed 35µg/m^3 35 times a year and the specified annual average concentrations for PM10 and PM2.5 are 28µg/m^3 and 17µg/m^3, respectively.

[246] https://www.epa.ie/environment-and-you/air/

[247] EPA, Air Quality in Ireland 2019

[248] https://www.epa.ie/publications/research/air/Research-Report--149-with-covers.pdf

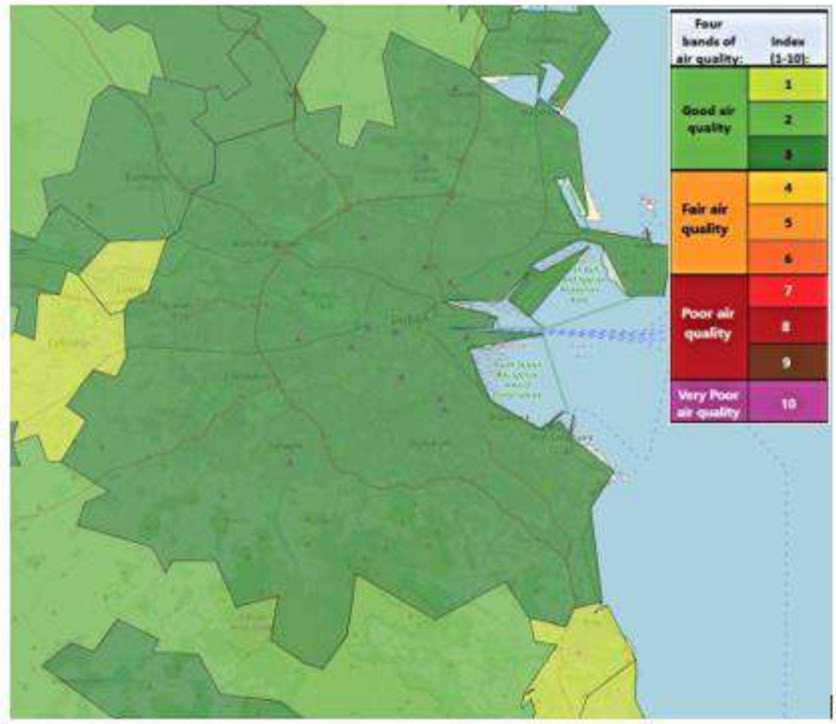


Figure 123: Air quality index for Dublin. Source: EPA Maps

Even though the air quality in Ireland is generally good, there are, however, localised issues in certain cities. This is the case in Dublin, when in 2019 there was an exceedance of the EU annual average legal limit values at one urban traffic station in Dublin due to transport pollution. The EPA states that the indications show that Dublin will exceed EU limit values for NO_2 at further monitoring stations in the future, therefore reducing pollutants is essential. Even though new standards for car emissions have resulted in cleaner fuels and technology has reduced emissions, Ireland has still seen an increase in both the number and cars and their engine sizes. There has also been a shift to diesel engines in recent years, which are lower in CO_2 but are higher in particulate matter. Therefore, a shift from the burning of solid fuel to cleaner, more energy efficient methods of home heating, such as heat pumps and district heating, and a move away from the use of private diesel/petrol vehicles to alternative modes of transport such as walking/cycling and electric vehicles (EVs) will result in cleaner air and a healthier environment for citizens.

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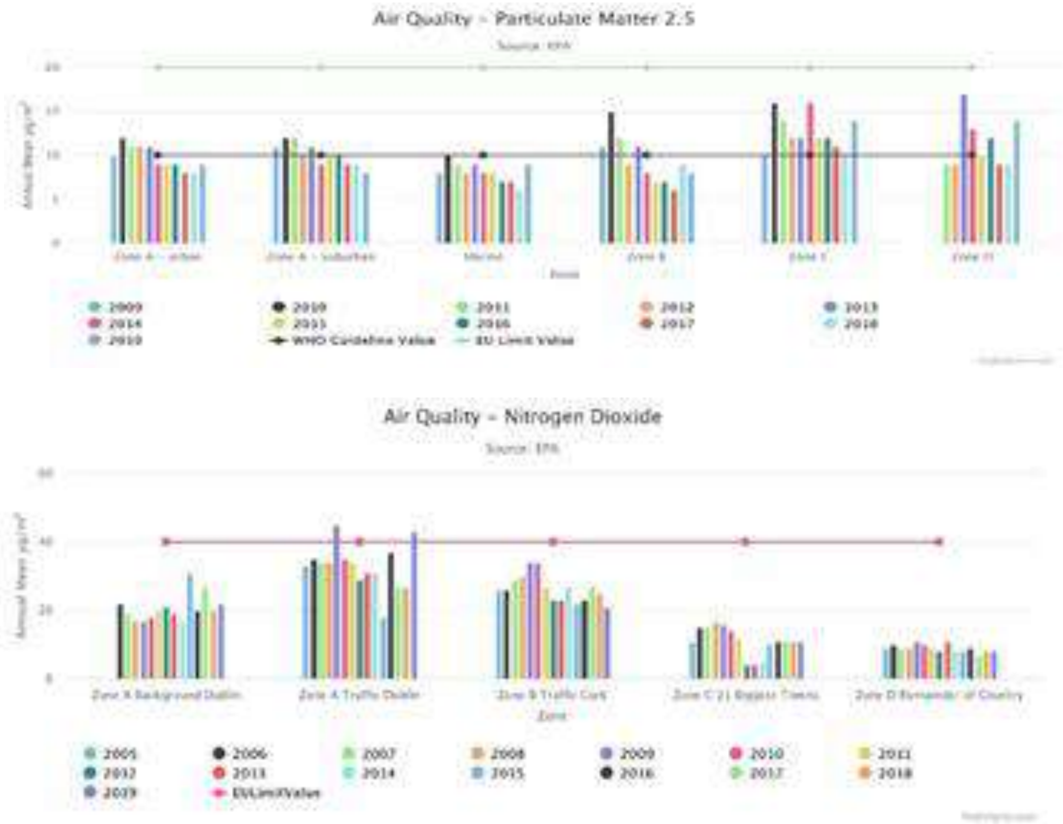
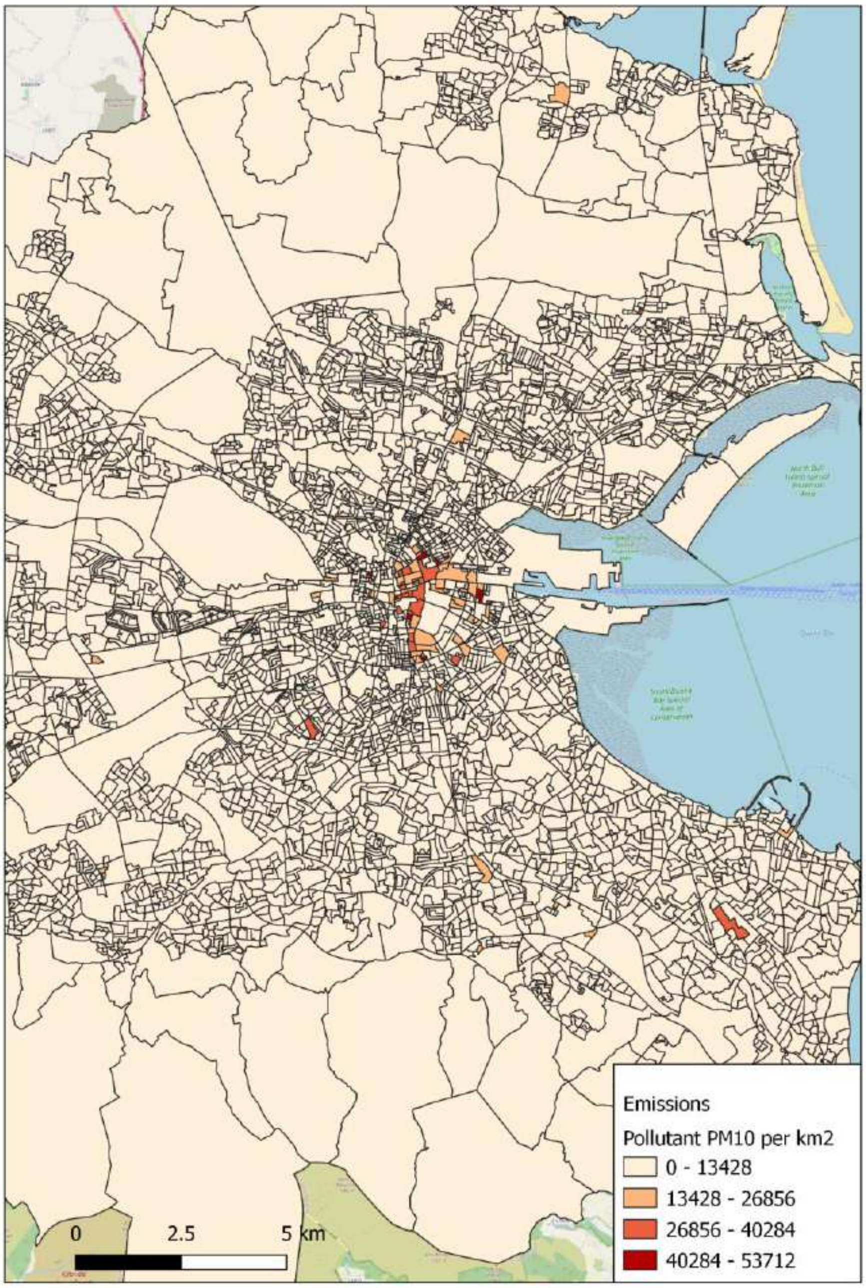


Figure 124: Air Quality PM10, Particulate Matter 2.5 and Nitrogen Dioxide. Source: EPA


Emissions
Pollutant PM10 per km2
0 - 13428
13428 - 26856
26856 - 40284
40284 - 53712
0
2.5
5 km

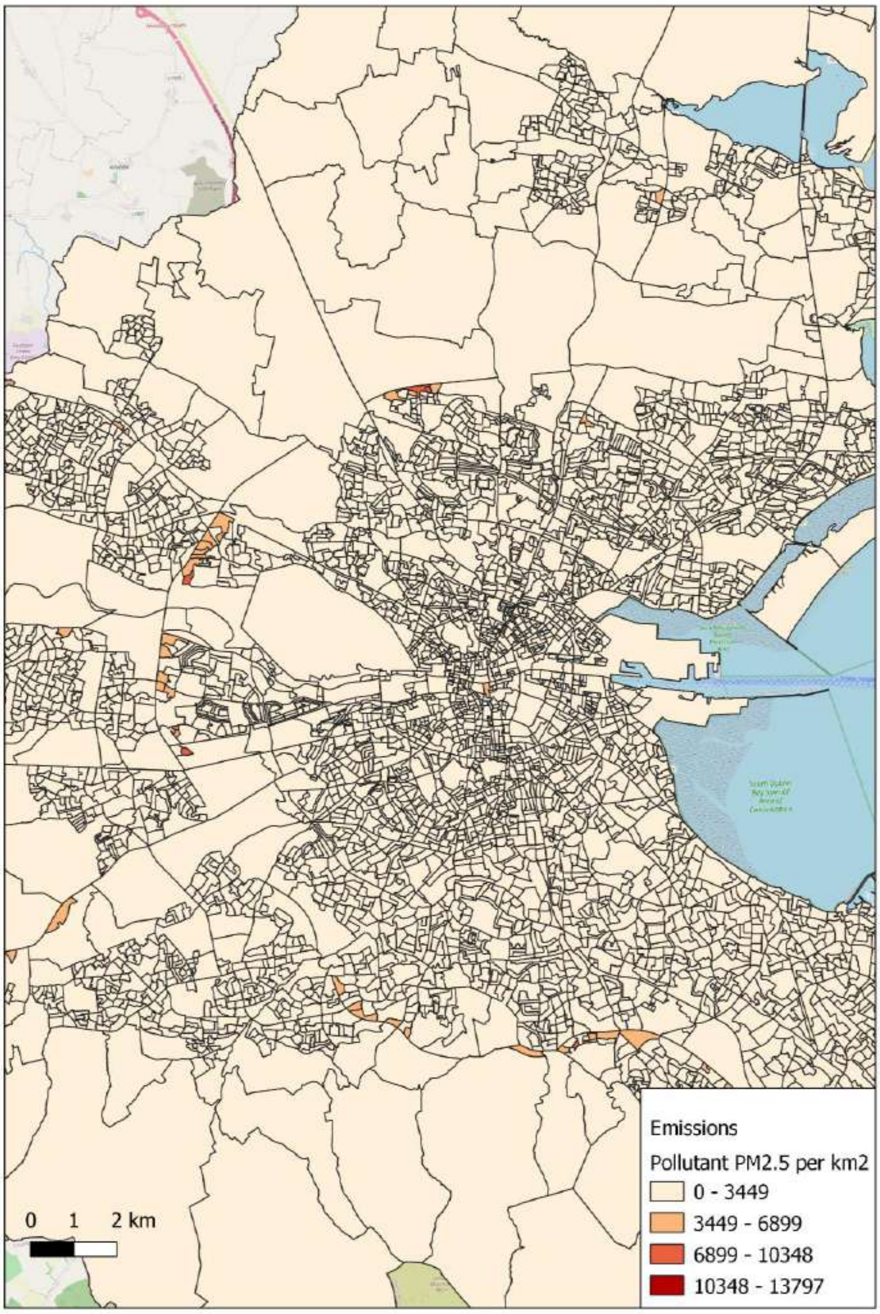


Figure 125: Air Quality - PM10 & PM 2.5 in the Dublin Region

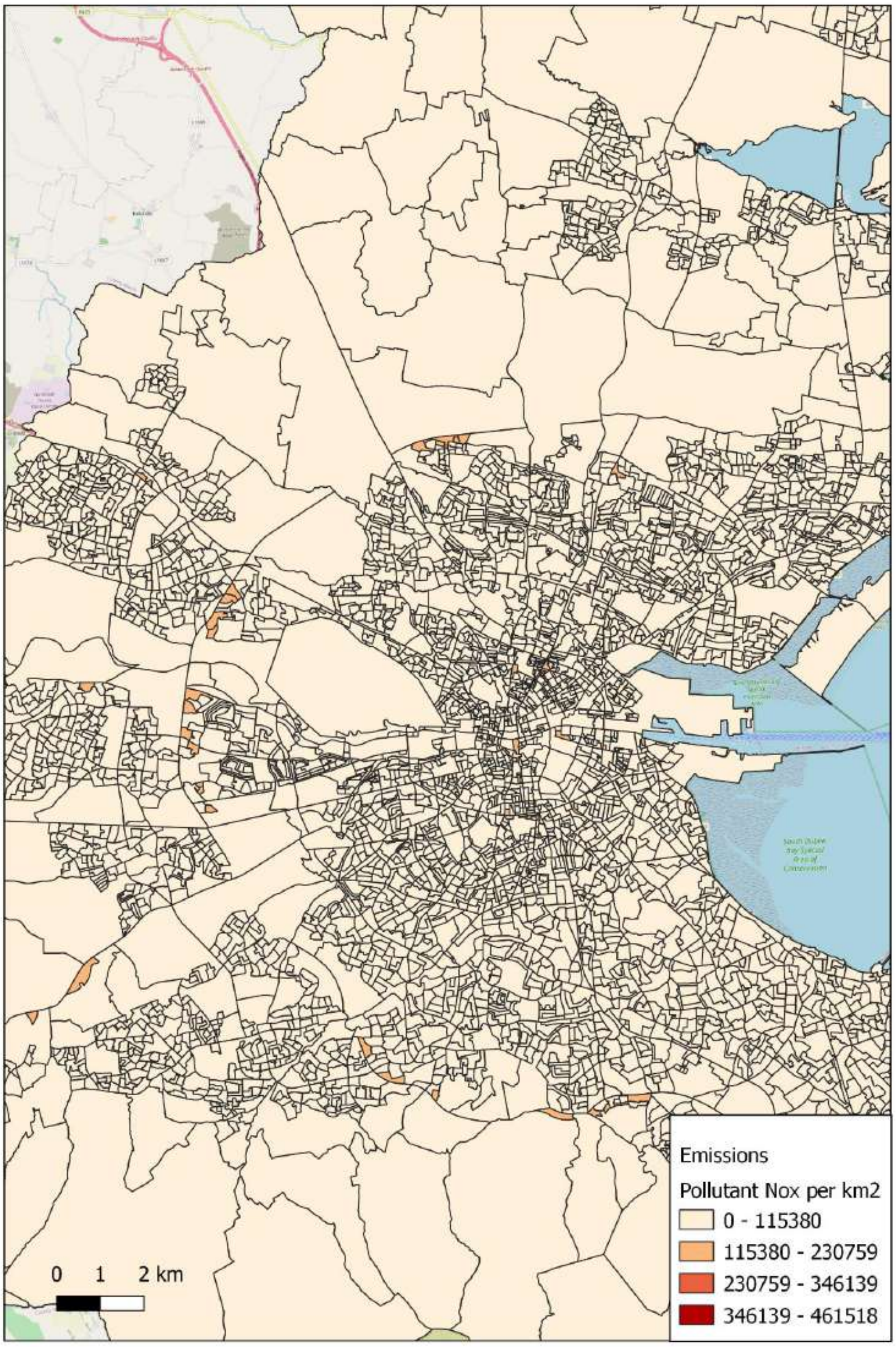


Figure 126: Air Quality - Nox in the Dublin Region

Low-Carbon Technologies, Renewable Energy and Emission Reductions

Throughout this document, Codema has recommended ways to reduce emissions in the county. If the Dublin Region were to carry out all the suggested recommendations, it could potentially reduce emissions by a total of 4,103 ktCO_2 by the year 2030 and 8,240 ktCO_2 by 2050, through the uptake of low-carbon technologies and increased renewable energy generation.

Table 60: Carbon Reduction Potential by 2050

	Reduction in $ktCO_2$ by 2030	Reduction in $ktCO_2$ by 2050
Electricity/ Renewable Energy Generation & Storage	2,047	4,795
Heating/ Low Carbon Technologies/ Building Fabric Upgrades	1,212	1,783
Transport	844	1,662
Total	**4,103**	**8,240**

Reducing Costs

Besides reducing emissions, technologies recommended in this report help increase renewable energy and lower energy costs. As can be seen from the table below, wind and solar energy in the Dublin Region can potentially generate 14,780 GWh of renewable energy by 2050. This increase in renewable energy can greatly help reduce the Dublin Region's heavy reliance on fuel imports and make use of indigenous renewable resources.

Besides an increase in local renewable energy, these renewable technologies (onshore and offshore wind, USSPV and building integrated solar PV) can decrease energy costs by a total of €519 million per year. Building integrated solar PVs help reduce the unit cost of electricity from 24c/kWh to 11c/kWh[249] and wind can reduce the unit cost to 21c/kWh.

Table 61: Wind and Solar Potential in the Dublin Region

Technology	Increase in RE Potential by 2050 GWh	tCO_2 Saved by 2050	Reduction in Energy Costs in €
Onshore Wind	267	86,569	8,357,100
Offshore Wind	10,761	3,492,052	336,819,300
Utility Scale Solar PV	1,057	343,036	138,784,100
Building Integrated Solar PV	270	87,763	35,451,000
Total	**12,355**	**4,009,420**	**519,411,500**

District heating networks can help reduce heat costs for customers by around 5-10% on counterfactual costs. Installation of heat pumps (have a 300% efficiency, whilst gas boilers are 85% efficient) and building fabric upgrades help improve buildings' efficiency, upgrades also reduce heat losses, which result in reduced heating demands and costs.

In the transport sector, research has shown that walking benefits society to the value of €0.37 per kilometre travelled, while cycling benefits individuals and society by up to €1 per km. This cost-benefit-analysis takes into account parameters such as health impacts, GHG and local air pollutants, noise pollution, land use and infrastructure, travel time and congestion.[250] Figures published by the AA suggest that the annual cost of running a family car in Ireland is

[249] Ricardo Energy & Environment, 2020. Economic and Policy Advice to Support Design and Implementation of the New Microgeneration Support Scheme in Ireland

[250] https://www.sustrans.org.uk/bike-life/bike-life-dublin-metropolitan-area
https://www.researchgate.net/publication/330184791_The_Social_Cost_of_Automobility_Cycling_and_Walking_in_the_European_Union

approximately €10,700 per year.[251] Recent research carried out in Germany similarly found that the cost of running a car there ranged from €6,700 per year to €12,900 per year.[252] This just represents the cost to the individual, and does not factor in external costs. The same German study found that the external social costs of car ownership come to approximately €5,000 per year on top of this, or €0.32/km for a typical family car. Assuming a similar value would hold true for Dublin, cars could be incurring a societal cost of up to €2.8 billion per year on the county at present. On the other hand, walking and cycling currently save Dublin over €258 million per year. Getting more people out of cars and on to active travel or public transport could therefore result in huge societal benefits for Dublin.

Energy cost reductions incurred from improved building fabric upgrades and low carbon heating technologies can help to reduce areas that are in or at risk of fuel poverty. Fuel poor households are households whose fuel costs are above the household's income; this can be due to an inefficient dwelling, resulting in high energy bills, and low income. Therefore, improvements in the housing stock and low-carbon, energy efficient technologies are essential to reduce energy demand in energy poor areas. The deprivation map shown below shows the measure of deprivation for small areas in the Dublin Region, with areas of high affluence shown as green and least affluent areas in red. The deprivation index helps policy makers and researchers to identify unprivileged areas and has demonstrated strong correlations with a range of health and social outcome measures across many countries.

[251] https://www.theaa.ie/aa/motoring-advice/cost-of-motoring.aspx
[252] https://www.sciencedirect.com/science/article/pii/S0921800921003943

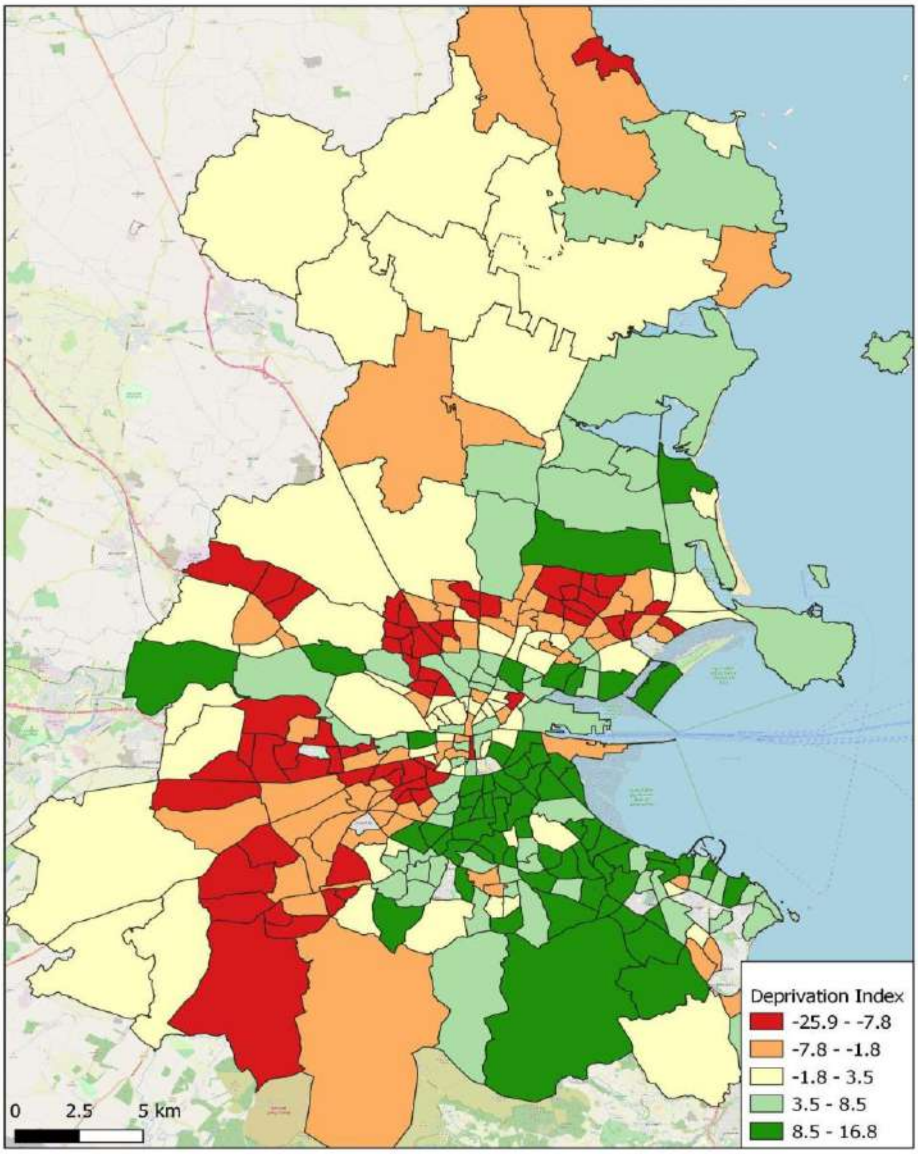


Figure 127: Deprivation Map. Source: Census 2016

The map below displays the outputs of the CSO 2016 Deprivation Index (DPI) Results coupled with BER & Population Data at Electoral District level. The DPIs are constructed using ten key socio-economic indicators. The scores are then labelled accordingly as; > 30 - Extremely Affluent, 20 to 30 - Very Affluent, 10 to 20 - Affluent, 0 to 10 - Marginally Above Average, -10 to 0 - Marginally Below Average, -20 to -10 Disadvantaged, -30 to -20 - Very Disadvantaged , < -30 Extremely Disadvantaged. To identify energy poverty areas, BERs with a D1 rating or poorer have been coupled with unemployment (greater than 20%) and a DPI of less than -10 (disadvantaged).

The areas identified as at risk of energy poverty (listed below and shown in red on the map) should be prioritised for energy efficiency upgrades and investment schemes to finance energy efficiency measures needed to alleviate energy poverty. This will benefit the area with their improved quality of life, especially for the vulnerable and can help ensure a more just transition for all.

Electoral districts identified as at risk of energy poverty:

- Ballybough A
- Cabra West A
- Cabra West B

- Clondalkin-Rowlagh
- Clonskeagh-Belfield
- Finglas North A
- Finglas North B
- Finglas South A
- Finglas South C
- Finglas South D
- Inns Quay A
- Kilmore C
- Priorswood D
- Decies
- Drumfinn
- Inchicore B
- Kilmainham A
- Kimmage A
- Kylemore
- Merchants Quay A
- Merchants Quay E
- Tallaght-Avonberg
- Wood Quay A

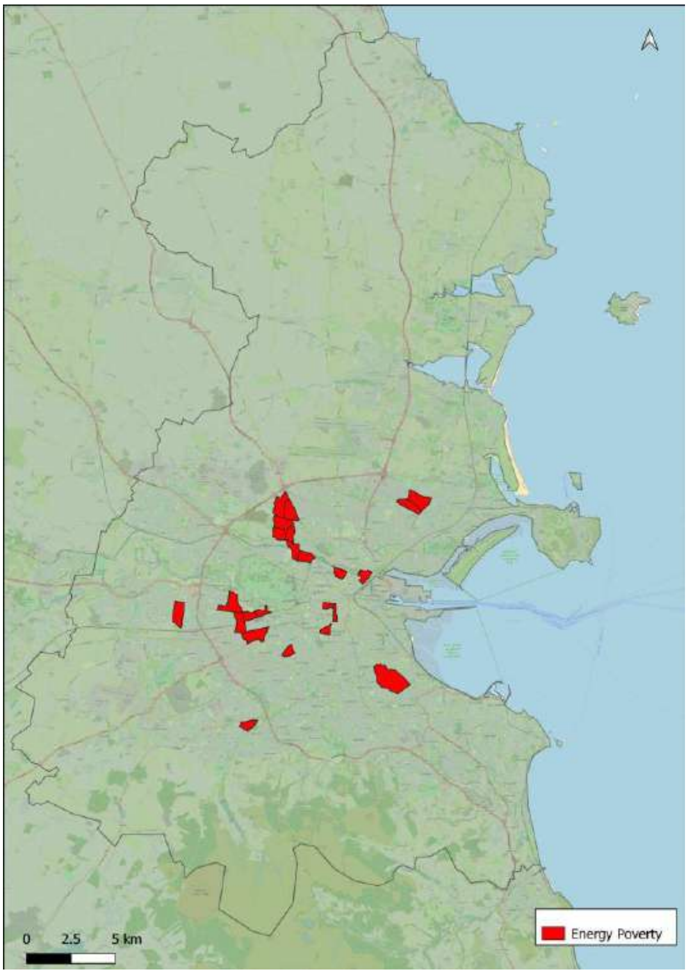


Figure 128: Energy Poverty by Electoral District

Shadow Price of Carbon

The shadow price of carbon is the estimated abatement cost for Ireland to remove emissions from the atmosphere. It is used to account for external costs from GHG emissions. The shadow price of carbon has become more important now due to legally binding GHG emission reduction targets and it is thus imperative that the assessment of projects include an appropriate valuation of the cost that society will bear in dealing with the removal of GHGs rising from the project. The use of a shadow price of carbon has become a standard part of Government project evaluation frameworks globally. It was introduced into the Irish Public Spending Code in 2009 and has been modified periodically.

'A shadow price is a hypothetical cost placed on a commodity that is not ordinarily quantifiable as having a market price…an individual project may not have to pay any direct cost for the greenhouse gas emissions it may give rise to. However, since the country as a whole has legally binding targets to reduce greenhouse gas emissions, the cost of these increased emissions will be a burden on society.'[253]

If we were to apply the shadow price of carbon to the total avoided emissions (from renewable energy generation, low carbon heating technologies, building fabric upgrades and transport) over the lifetime of the masterplan, this would result in a total avoided cost of over €24 billion. This avoided cost would be better invested in renewable sources of energy, energy efficient homes and heating options to reduce emissions and citizens' utility bills.

Table 62: Total Avoided Costs

Year	Shadow price of carbon in €/ktCO_2	Emission Reductions in ktCO_2	Total Avoided Costs (in million €)
2022	46	444	20.40
2023	52	884	45.97
2024	59	1,325	78.15
2025	66	1,765	116.50
2026	73	2,206	161.01
2027	80	2,646	211.69
2028	86	3,087	265.46
2029	93	3,527	328.03
2030	100	3,965	396.47
2031	105	4,178	438.74
2032	110	4,392	483.15
2033	116	4,606	534.30
2034	122	4,820	588.01
2035	128	5,034	644.29
2036	134	5,247	703.14
2037	141	5,461	770.01
2038	148	5,675	839.87
2039	155	5,889	912.73
2040	163	6,102	994.68
2041	171	6,316	1,080.06
2042	180	6,530	1,175.38
2043	189	6,744	1,274.55
2044	198	6,957	1,377.56
2045	208	7,171	1,491.60
2046	218	7,385	1,609.91
2047	229	7,599	1,740.10
2048	241	7,812	1,882.80
2049	253	8,026	2,030.63
2050	265	8,240	2,183.59
Total			**24,379**

[253] DPER, 2019. Valuing Greenhouse Gas Emissions in the Public Spending Code

Generating Jobs

Non-energy benefits are often overlooked in the appraisal of energy efficiency projects. Under the Long-Term Renovation Strategy, Member States are required to provide an evidence-based estimate of expected energy savings and wider benefits. The Energy Performance Building Directive (EPBD) explicitly refers to co-benefits relating to health, safety and air quality, and the Commission's Recommendation (EU) 2019/786 of 8 May 2019 on building renovation goes even further and includes examples of co-benefits relating to the reduction of whole life carbon, labour productivity gains, GDP, increased employment in the building sector, and a reduction in energy imports.

Investing in clean energy projects helps improve air quality through renewable energy generation, reduces emissions and improves economic status through the generation of local jobs to facilitate this. Thus, the demand for renewable energy to meet energy demands and the need for energy security is an opportunity for both innovation and employment.

Employment Potential

There are several types of potential employment created within the renewable sector. These are outlined below[254]:

- **Direct employment** – jobs provided by companies directly involved in the core activities pertaining to renewable energy generation, such as contractors and crews hired to build the plant. Direct employment can be broken down into long and short-term employment:
  - **Long-term employment** – jobs that are maintained for several years, such as onsite maintenance staff
  - **Short-term employment** – temporary jobs that are generated for specific aspects of implementation of renewable energy projects, such as construction work
- **Indirect employment** – jobs provided by companies that support the core activities of primary companies, such as specialist engineers and legal services
- **Induced employment** – tertiary employment, jobs generated because jobs generated by the sector increased the purchasing power of people involved in the industry
- **Induced investment** - refers to investment in capital stock and purchasers' equipment as a knock-on result of an economic stimulus or shock. The greatest impact is on the construction industry

Solar PVs

A study by the International Renewable Energy Agency (IRENA) has shown that around 12 million people in 2020 were employed in the renewable energy sector, a third of this workforce (4 million workers) are employed in the solar PV industry[255]. Solar has become one of the fastest growing industries in the renewable energy sector, with the main driving force for this growth being the decrease in technology costs, which has led to higher demand. Policies for achieving renewable energy targets set at the EU and national levels to meet energy demands and reduce GHG emissions have also been a driving factor.

Using the Irish Solar Energy Association's (ISEA)[256] information on job creation through solar PV projects, Codema estimated that 5,845 jobs could be generated from potential building integrated PV projects in Dublin from 2021 to

[254] IRENA,2013; EPIA,2012. Sustainability of Photovoltaic Systems

[255] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Oct/IRENA_RE_Jobs_2021.pdf

[256] Irish Solar Energy Association. Jobs in Solar PV

2050. Of this, over 3,800 jobs are direct jobs in construction and in the operation and maintenance of the solar PVs, and indirect jobs may total 1,937 jobs.

Table 63: Potential Job Generation from Solar PV Projects in the Dublin Region

Potential Jobs Created from Building Integrated PV Projects		Jobs/ MW	Jobs Created
Direct	Construction	11	3,804
	O&M	0.3	104
Total Indirect[257]		5.6	1,937
Total Jobs			**5,845**

Utility-scale PV, which in this report has been highlighted as the biggest opportunity for Dublin, can greatly impact job creation. The EU Solar Jobs Report for 2021[258] suggests that utility-scale solar PV (USSPV) jobs contribute between 19% to 38% of solar jobs in the EU. Assuming that USSPV can generate an average of 28.5% per MW of jobs created from rooftop PV, direct jobs created would equate to over 5,000 and almost 2,500 indirect jobs from USSPV.

Onshore and Offshore Wind

Onshore wind deployment has a consistently positive impact on the Irish economy and net employment in 2020. SEAI's report on Macroeconomic and Net Employment Impacts of Ireland's Renewable Heat and Electricity Targets in 2020[259] estimated that 4,400 net jobs were created in 2020 in Ireland, of which 2,000 were direct jobs in construction, 500 in direct operations and maintenance and the rest in the supply chain. This is also reflected in the GDP for 2020, which preliminary results indicate could increase by €305 – €585 million as a result of building new wind farms and expansion of the grid.

From SEAI's report on onshore wind deployment,[260] It was estimated that approximately 0.34 jobs per MW are long-term jobs directly created to support operation and maintenance of new wind turbines and in the wider electricity supply sector. This falls in line with the European Wind Energy Association estimates for direct O&M employment in Europe. Using these figures, Codema estimated that 429 jobs could be generated from potential onshore wind projects in Dublin from 2021 to 2050. Of these, 235 jobs are direct jobs in electricity supply and construction, 67 jobs are indirect employment, and investment demand can help generate 83 additional jobs.

[257] Assumed to be 50% of direct jobs in line with lower limit figures outlined in https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2013/rejobs.pdf

[258] EU Solar Jobs Report 2021. Towards Higher Solar Ambitions in Europe https://www.solarpowereurope.org/wp-content/uploads/2021/11/SPE-EU-Solar-Jobs-Report-2021-1.pdf?cf_id=43484

[259] SEAI, 2020. Macroeconomic and Net Employment Impacts of Ireland's Renewable Heat and Electricity Targets in 2020

[260] SEAI, 2015. A Macroeconomic Analysis of Onshore Wind Deployment to 2020

Table 64: Potential Job Generation from Onshore Wind Energy Projects in the Dublin Region

Potential Jobs Created from Onshore Wind Energy		Jobs/ MW	Jobs Created
Direct	Elec Supply	0.34	57
	Construction	1.07	178
Indirect		0.40	67
Induced		0.27	45
Investment demand		0.50	83
Total Jobs			**429**

Meanwhile, offshore wind can also potentially increase employment potential for this sector drastically. EirWind's Blueprint for Offshore Wind in Ireland 2020-2050[261] suggests that *'6.5-7.3GW of domestic offshore wind development would support between approximately 12,000 and 13,500 direct and indirect jobs in the domestic supply, with a total Gross Value Added (GVA) impact of circa €2bn for the period 2020-2029.'* This means that if we were to apply these figures to this masterplan's potential energy generated from offshore wind (3GW), this would result in over 5,200 direct jobs in the offshore wind industry.

Building Fabric Upgrades and Improvements in Heating Technologies

A research report, A Survey of the Employment Effects of Investment in Energy Efficiency of Buildings[262], commissioned by the Energy Efficiency Industry Forum to address job creation potential from the Energy Efficiency Directive, estimates that 19 new direct jobs can be expected when investing €1 million in upgrading the energy efficiency of our building stock in the construction sector. Furthermore, it is suggested that the vast majority of these jobs will be local and non-transferable, which would mean that the vast majority of these local job creation would directly impact the local economy. Assuming that 19 direct jobs can be expected for each million euro invested in building fabric upgrades, for a cost of €1,620 million (identified in this report as the cost to retrofit 320,000 buildings), this would mean that a total

[261] EirWind Blueprint for offshore wind in Ireland 2020-2050, A Research Synthesis. https://www.marei.ie/wp-content/uploads/2020/07/EirWind-Blueprint-July-2020.pdf

[262] How Many Jobs? A Survey of the Employment Effects of Investment in Energy Efficiency of Buildings. https://euroace.org/wp-content/uploads/2016/10/2012-How-Many-Jobs.pdf

of 30,780 jobs will be created from building retrofits in the Dublin Region, an average of over 1,060 jobs per year to 2050.

Heat pump installation for heat pump ready homes would also further increase the potential number of jobs created. From IEA's[263] 'Job creation through investment in heat pumps in the Sustainable Recovery Plan' has identified that the highest number of jobs lay in manufacturing HPs, which generate 4 jobs per million Euro spent in HPs, followed by installation and maintenance jobs, which generate 2 and 1 job per million euro spent, respectively. For the Dublin Region, the total capital cost of installing 78,128 heat pumps (excluding the building fabric upgrades) is €1.2 billion. This would create the equivalent of 382 direct local jobs per year for the period up to 2050.

District Heating can also stimulate the local economy, where jobs created are in proportion to the extent of the network's overall trench length and heat demand served. It is estimated that approximately 45% of the capital cost of developing DH networks is required for installation of the network and it's ancillaries.

This portion of the investment will benefit local workers involved in areas such as civil engineering works, and installation of the plant. In addition to this, as DH predominantly utilises local heat sources to produce heat (rather than imported fossil fuels) a significant proportion of the money customers pay for heating their homes also stays in the local economy. This DH roll out optimised to 2050 would require 2,421.8km of distribution pipework and 4,209.5km of customer connections estimated to cost €5.7 billion. The total capital cost of achieving this target is estimated at €7.7 billion with the majority of this investment staying within the local economy. This would create the equivalent of 4,354 direct local jobs per year for the period 2021 to 2050.

[263]IEA, Job creation through investment in heat pumps in the Sustainable Recovery Plan, IEA, Paris https://www.iea.org/data-and-statistics/charts/job-creation-through-investment-in-heat-pumps-in-the-sustainable-recovery-plan

Appendix G - Definition of Future Proofing for District Heating

Within identified district heating zones where a network does not already exist but there is sufficient heat demand density to support a network, all buildings should be future-proofed for connection to a DH network. This shall include:

- Ensuring new or upgraded buildings install/maintain centralised[264] or communal wet heating systems with adequate controls such as thermostatic radiator valves, BMS, etc. to ensure the systems operate efficiently (with low return temperatures of 40°C or lower) and a flanged connection to allow future coupling to a DH network.
- Locating plant rooms within buildings so that it reduces the pipe lengths required to connect to a DH network and where possible facilitates access to the plant room from outside for any maintenance, i.e. plant rooms located adjacent to external walls (nearest the proposed/existing DH route, where possible) on lower levels (basement or ground floor) with secure external door for access.
- Allocating space in plant rooms for DH heat exchangers.
- Safeguarding pipe runs within the development site for future connection to a DH network up to the boundary of the site.
- Considering the provision of energy centres within new developments for heat generating technologies and/or thermal storage, which could supply a local low-carbon DH network. Again, appropriately located to reduce pipe runs and provide easy access for maintenance.

[264] In the case where a building may consist of multiple dwellings or commercial premises a centralised system refers to one centralised plant room in the block not a centralised heating system in each premises.

Appendix H - Common Assumptions

This section sets out the main assumptions which are common to multiple sectors analysed in this report.

Carbon Emission Factors

The carbon emissions factors for electricity is based on analysis of the national electricity production performed by MaREI to 2030 and then assumes a linear reduction to zero by 2050. The decarbonisation trajectory of gas is based upon a target of 1.6 TWh of green gas by 2030 in the Climate Action Plan. In 2050, the gas network is assumed to reach 11.6 TWh of biomethane injection and have a mix of 20% hydrogen (20% by volume which equates to 7% by energy content), based on current assumed limitations of the gas networks and existing appliances to transport and burn gas with higher hydrogen concentrations.

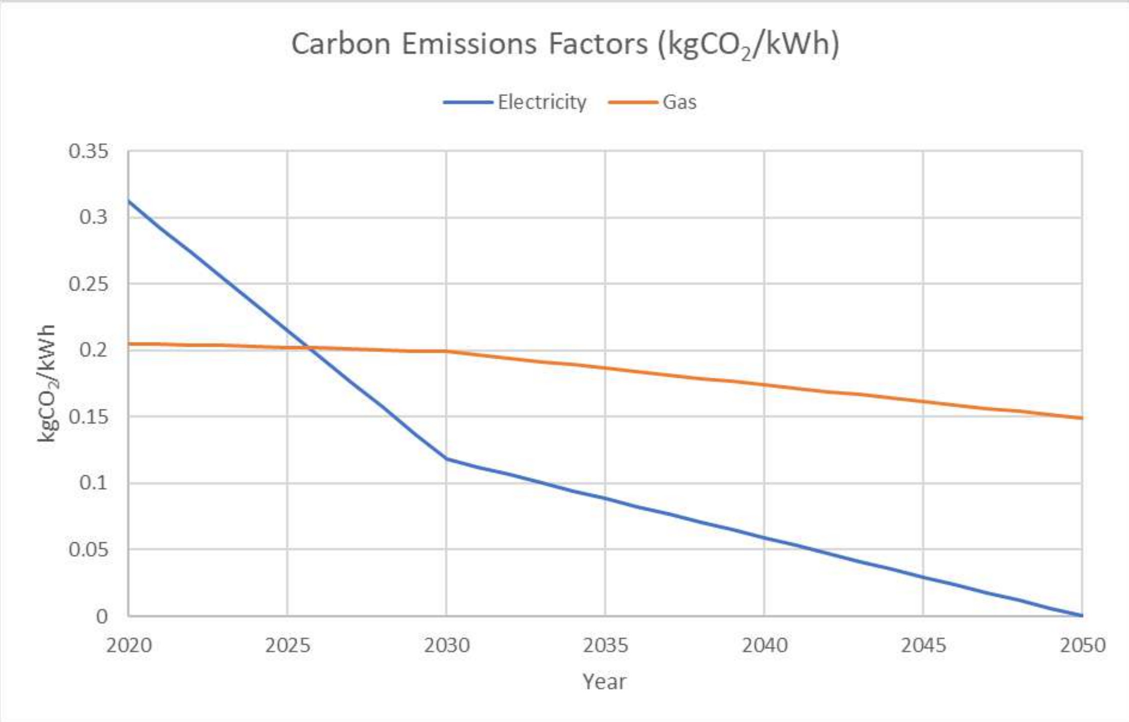


Figure 129: Electricity Grid and Gas Carbon Emission Factors.

When assessing the emissions savings from renewable electricity generation such as solar and wind, the 2019 emissions factor of 0.3245 tCO_2/MWh was used. The most recent available grid emissions factor was for 2020 at the time of writing this report. However, the 2019 figure was considered more representative as 2020 was a particularly windy (high renewable generation) year with lower than usual demand due to the mild winter. This factor was also used, as over the life of this masterplan it is assumed that the current generation mix of fossil fuel and older renewable generation is what will be replaced by these new renewables.

Population Growth

The Economic and Social Research Institute (ESRI) has published population projections and annual average population growth rates for Ireland, this is further broken down by region (table below). For Dublin, it has been estimated that the population from 2016 to 2040 would increase annually by 0.9%.

Table 65: ESRI's Population Projections and Annual Average Population Growth Rates by Region[265]

[265] https://www.esri.ie/system/files/publications/RS70.pdf

	Population ('000s)			Annual Average Growth		Population Share	
	2011	2016	2040	2011-2016 %	2016-2040 %	2016	2040
Border	514.9	523.2	589.0	0.3	0.5	11.0	10.5
Midland	282.4	292.3	330.5	0.7	0.5	6.1	5.9
West	445.4	453.1	534.1	0.3	0.7	9.5	9.5
Dublin	1,273.1	1,347.4	1,639.8	1.2	0.9	28.3	29.1
Mid-East	531.1	560.0	707.5	1.1	1.1	11.8	12.6
Mid-West	379.3	385.0	449.4	0.3	0.7	8.1	8.0
South-East	497.6	510.3	585.4	0.5	0.6	10.7	10.4
South-West	664.5	690.6	799.2	0.8	0.7	14.5	14.2
State	4,588.3	4,761.9	5,634.8	0.8	0.8	100.0	100.0
Northern and Western	837.4	847.4	961.6	0.2	0.6	17.8	17.1
Eastern	2,209.5	2,328.5	2,839.2	1.1	0.9	48.9	50.4
Southern	1,541.4	1,585.9	1,833.9	0.6	0.7	33.3	32.5

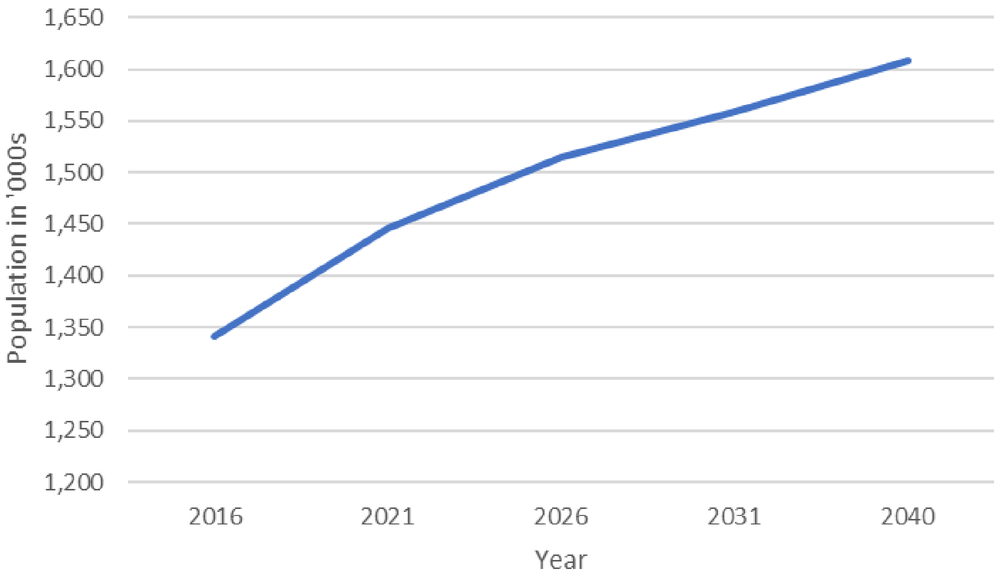


Figure 130: The Dublin Region Population Projections

<u>Lifespan of Low-Carbon Technologies</u>

The reinvestment cost of each technology is determined by its typical lifespan. The table below sets out the assumed lifespan for each technology.

Table 66: Technology Lifespan

Sector	Technology	Lifespan (years)
Heat	Heat Pump	15
Heat	District Heating Network	50
Heat	District Heating Production Plant	25
Heat	District Heating Substations	25

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